# LIGHT INTENSITY EFFECTS ON METABOLISM, GROWTH, AND YIELD COMPONENTS OF PEANUTS

By

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THIS DISSERTATION IS DEDICATED TO
THE AUTHOR'S PARENTS,
BROTHER, AND SISTERS.

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# LIGHT INTENSITY EFFECTS ON METABOLISM, GROWTH, AND YIELD COMPONENTS OF PEANUTS

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Florunner peanuts (Arachis hypogaea L.) were shaded at selected reproductive stages (flowering, pegging, pod filling, and maturity) in a two-year field experiment.

In the 1975 experiment, 75% shade was applied for ten consecutive days at four different stages to study the effects of shading on vegetative growth and yield components of peanuts. In the 1976 experiment, three durations (7, 14, or 21 days) of 75% shade were applied at flowering, pegging, pod filling, and maturity. The objective was to determine which periods of the peanut life cycle were most sensitive to low light intensities, in terms of shade effects on fruit growth rate, metabolism, and yield components of peanuts.

Flower frequency, peg development, pod formation, and dry weight accumulation in vegetative and reproductive components were observed at regular sampling intervals on control and shaded peanuts. Pegs and pods were classified in five categories by number and weight. The 21-day shading treatment at pod filling (83 to 104 days after planting) was selected for a study of fruit growth rate by tagging, at weekly intervals, all pegs penetrated into the soil since the last weekly tagging. The tagged fruits were harvested every eleven days and fruit numbers, dry weights, and inner shell colors recorded according to week of peg formation. Shells and seeds were weighed and analyzed for carbohydrates and oil.

Shading at peak flowering stage reduced the number of flowers per plant. Flowers open at the time of shading did not produce pegs. Shading at pegging and pod filling reduced total peg and pod number and reduced fruit dry weight in both experiments. Shading for 21 days during the pod filling stage caused the greatest yield loss (30%). However, the 21-day shading at flowering stage did not reduce yield, as plants had enough time to recover from the loss of active flowers to produce a normal fruit load. Shading during maturity slightly decreased yield by decreasing the percentage of fully-formed fruits, and reducing seed growth of smaller, later fruits. The period of pod filling, from 83 to 104 days after planting, seemed to be the period most sensitive to low light intensity with respect to yield reduction.

Experimental results were compared to results from PENUTZ simulation which predicted the effect of shading on vegetative and reproductive development and final yield. The predicted yield from the simulation model was comparable in ranking, but somewhat lower than the experimental results.

Low light intensity also changed fruit and seed metabolism. Shade increased the oil percentage of older fruits, regardless of the date of fruit formation. Sucrose content of fruits was reduced, but shade caused no effect on sucrose percentage. Shade increased starch and reducing sugars in the seeds, but had no effect on reducing sugars in the shells. Total carbohydrates were higher in shaded fruits and were positively correlated with the oil content of these seeds.

Shade, when applied at critical periods, decreased the peanut yield up to 30%. Florunner peanut compensated well for stress conditions. Shade caused major reduction in number of fruits or pegs, but had relatively minor, although significant, effects on fruit growth rate, and carbohydrate and oil metabolism.

# INTRODUCTION

Peanut (Arachis hypogaea L.) may have one or more periods during development when low light intensity is particularly detrimental to high yield.

Studies of the light requirements of soybean (Glycine max (L.) Merrill) and peanut suggested that the need for light intensity is most critical during the reproductive stage of growth.

Knowledge of the critical crop growth stages for light may aid managers in their decision on planting and harvesting, and may facilitate multiple cropping. Some understanding of the sensitivity of peanut to low light intensity at various stages of their life cycle may help explain their response under cloudy skies in humid tropics.

The quality and quantity of peanut seed components are also very important. Knowledge of peanut metabolism will provide a better understanding of peanut quality. However, more research is needed to identify the critical periods for the climatological factors which influence the yield and quality of peanuts.

The present investigation was conducted to determine whether Florunner peanut has critical periods during which high light intensity is needed to produce the optimum fruit and seed numbers and to produce maximum yield of oil and protein per unit land area.

# LITERATURE REVIEW

During the past two decades peanut yields have increased markedly in the United States. The yield increase for peanuts was 165%, while soybean and corn (Zea mays L.) yields increased 32 and 135%, respectively, during this same period (Agricultural Statistics, 1972). In Florida, peanut yields have steadily increased. During the 1920's, the highest peanut yield was 1750 kg/ha obtained by Stokes, with the Florida Runner variety. In experiment station tests, the next record yield, 2930 kg/ha, was obtained by Stokes (Killinger et al., 1947) using Dixie Runner variety. In 1959, a new yield breakthrough occurred when Harris, Myers, and Clark (1961) produced 5340 kg/ha with the Early Runner variety. The most recent experimental yield record of 6070 kg/ha was set by Norden (McCloud, 1973) with Florunner variety. The peanut farmers in Florida are regularly producing over 4.5 tons per ha. Record yields in the United States have exceeded 6.5 tons per ha and a world record yield of 7500 kg/ha has been achieved in Israel (McCloud, 1974).

At these high yield levels, climatological factors may set the ceiling for peanut yields. Growth analysis studies of the dry matter production of peanut were first conducted by McCloud in 1973, and computer modeling, PENUTZ (a physiological model for simulating the development and growth of peanut and for predicting peanut yield from climatological data), was first used by Duncan in 1974. Daily inputs of maximum and minimum temperature, precipitation, and solar radiation are used in this model. This model predicts peanut yield responses to climatological data and allows us to study such effects of low light intensity at different stages of growth on peanut yields.

## The Effects of Light Intensity on Yield Components of Field Crops

Research in corn (*Zea mays* L.), winter wheat (*Triticum aestivum* L.), sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merrill), and rice (*Oriza sativa* L.) has been devoted to understanding the interaction of the physiological development of plants and the effects of environmental factors (water, light intensity, temperature, nutrients, insects, and diseases).

Shading experiments with corn, winter wheat, sorghum, soybean, and rice have shown that yield is most adversely affected by low light intensity during the reproductive stage. Earley et al. (1966) studied the effect of degree and duration of shading on the growth and yield of corn; he concluded that grain yield decreased in a curvilinear manner as light intensity decreased. Shading delayed tassel, anther, and silk development regardless of the percentage of light reduction while 90% reduction in light intensity during the reproductive phase completely disrupted normal pollination. In a later experiment, he found that shading during the maturation stage decreased the yield more than 50%. There was a significant decrease in the number of corn kernels and dry weight of the plants. Prine (1977) determined the effect of light intensity on yield components of corn, and found that shading during silking caused the lowest number of seed per plant compared to an unshaded control and other shade treatment periods. In one season, he found the lowest number of kernels per plant occurred in the shade treatment beginning 10 days after silking. Kernel weight fluctuated slightly with a tendency toward higher weights when there were fewer seeds per plant. Kernel weights also tended to be lower if shading occurred during rapid kernel filling. Lowest plant yields resulted from the same shade periods as those causing the lowest number of kernels per plant.

In experiments on soybeans, Prine (1976) found more than 15% reduction in seed yield from 5- or 7-day shade treatments of 75%. Yield reductions occurred in shade periods just prior to flowering, after flowering, during pod enlargement stage, and during the seed filling stage. Shade during the pod enlargement stage usually resulted in fewer seeds per dm of row and increased seed weight. Shade during the seed-filling stage resulted mainly in reduced seed weight and yield with little change in seed number.

Grain yield of soybean and cowpea decreased significantly as light intensity decreased. This was related to reduced pod numbers per plant at the lower light intensities (Eriksen, 1977). Grain yield of bush bean was low at full daylight due to small seed size, and was highest at 70 and 45% daylight.

Reduced light during the period of rapid vegetative growth had a marked effect on ear number and top ear length of sweet corn (Burns and Andrew, 1976). Early and late inbred cultivars responded differently with low light intensity at different periods of growth. The early inbred tended to be more affected by early shade treatments and the late inbred by late treatments.

Pendleton and Weibel (1965) observed that decreasing light intensities during vegetative growth of wheat consistently decreased root weight more than the corresponding stem weight. He also found that wheat shaded during the entire growing season produced less grain but with an increased protein content. Shading from heading through maturity reduced yield more than shading during vegetative growth. He therefore concluded that decreased yields of winter wheat could be explained by both the direct effect of light on photosynthesis and the indirect effect of light on root development.

Pepper and Prine (1972) discovered two stages of sorghum plant development which were adversely affected by low light intensity. The first was the preboot vegetative stage (2 weeks before 50% anthesis), and the second was the milk and dough stage (3 weeks after 50% anthesis). Low light intensity during the first stage decreased the number of seeds per panicle, while shading during the later stage reduced seed weight.

Prine (1961) demonstrated that if lower leaves of the corn plant received more light than they normally would in high population plantings, yield per plant could be increased through development of more ears. Aluminum foil reflectors in row middles were used to reflect light to the lower leaves which ordinarily escaped plant interception. A yield increase of 1259 kg/ha of grain over that of the check plots resulted. In that report, Prine questioned whether light is critical in determining ear number per plant over a long or short period of time in plant development. Pendleton et al. (1967) obtained results similar to those of Prine (1961) in a corn study using aluminum reflectors to enrich the light environment. Pendleton reported that enriching the light environment resulted in shorter plants with larger stalks and more ears.

Prine (1963) further demonstrated the importance of the lower five leaves on the number of ears. By removing these lower leaves when 25% of the tassels had emerged, the number of ears per plant was significantly reduced. It was concluded that the lower five leaves contributed five times as much to yield at 1.98 plants/$m^2$ as they do at 3.96 plants/$m^2$ because at the lower plant population the lower leaves received considerably more light.

Prine and Schroder (1964, 1965) conducted two experiments using shades at different stages of maturity and enriching the light environment by topping plants in adjacent rows. They reported the presence of a critical period in which shade resulted in fewer ears per plant while light enrichment during the critical period increased the number of ears per plant. The weight per ear was found to be dependent on light intensity after the critical period.

Bowes et al. (1971) conducted an experiment with soybeans grown under different light intensities. They concluded that specific leaf weight and photosynthetic rate increased as light intensity increased within a given light source.

Schou et al. (1975) added supplemental light to soybeans growing in the field by placing Sylvania Grow Lux Wide Spectrum fluorescent lamps 13 cm from the treated row at three canopy levels--23, 46, and 69 cm--above the soil surface. Supplemental light during late flowering and early pod set caused as much as 15% increases in seeds, nodes, pod branches, pods per node, seeds per pod, and a higher oil content than normal plants.

Stansel et al. (1965), using shade treatments at different stages of rice plant development, reported that shading during the vegetative stage resulted in significant reduction in yield. His findings on rice are similar to those on corn, wheat, and oats. When rice was shaded during its reproductive stage, he found a decrease in the number of filled florets per panicle, in kernel weight, and the number of panicles per unit area.

Photosynthetic response of peanut plants is not well-known. Floral initiation does not require light saturation; however, flowering and development should be correlated with solar radiation and light intensity. Gillier and Silvestre (1969) suggested a relationship between light duration and the number of flowers produced.

Hudgens and McCloud (1975) concluded that the peak flowering period of Florunner was the stage most sensitive to a reduction of solar radiation intensity. Shading prior to the onset of flowering stage appeared to affect the distribution of pods around the main stem. Shading after peak flowering interrupted pod filling, resulting in a significant decrease in the percentage of extra large kernels.

With the same variety of peanut as above, Hang An and McCloud (1976) found that a reduction in light intensity at peak flowering stage reduced the number of flowers per plant, while flowers open at the time of shading did not produce pegs. Shading at the pegging stage significantly reduced peg and pod numbers and weight but increased the percentage of extra large seeds at harvest. Shading during the pod filling and maturing stages slightly decreased the number and dry weight of mature pods, and significantly increased the percentage of shriveled seeds at harvest.

If the peanut has a light requirement like other crops and similar to the previous experiments investigated by Hudgens and McCloud and by Hang An and McCloud, it would be expected that the most critical need for light would occur somewhere in the pod formation stage.

## The Effects of Light Intensity on Fruit Growth Rate and Its Metabolism

### Fruit Growth Rate

After the peg had attained its maximum penetration into the soil, the shell rapidly attained its maximum size and fresh weight (Patel and Seshadri, 1935). When the peanut fruit attained its maximum size, the shell contained only a weakly developed inner layer which collapsed on dessication. At this stage, the shell was composed mainly of fragile parenchymatous tissue containing a very small amount of total solids. After the peanut shell had developed to full size, its fresh weight declined very rapidly as the seeds expanded into the shell cavity. Although the fresh weight declined, the dry weight of the shell continued to increase slowly during the next week or two. The dry weight then remained steady for a time and finally declined slowly as seeds approached maturity.

The development of the seeds was very slight until the shell had reached its full size. After this lag, the fresh and dry weights of seeds increased rapidly. The rate of increase in fresh weight and dry weight was most rapid in the early stages of seeds enlargement. The rate then gradually declined for a period of more than a month, but it was difficult to determine exactly when further dry weight accumulation ceased (Schenk, 1961).

Different varieties followed the fruit growth pattern differently. The Virginia seeds produced a typical sigmoid development curve (Pickett, 1950). The Spanish seeds exhibited a somewhat different pattern of development. The rate of increase in dry weight appeared to be steady or actually accelerating until maturity. Development then appeared to cease abruptly. To some extent, this abrupt cessation of further development may have been due to back pressure which presumably built up in the seeds as they became tightly packed in the surrounding and restricting shell (Schenk, 1961).

Boote (1976) studied the fruit growth rate of Florunner peanut variety under normal conditions in a field experiment. He found that fruits set during the first four weeks of pegging had similar linear growth rates (33.5 mg/day/fruit) between 1 and 7 weeks of fruit age and accounted for 78% of the yield at 133 days. Fruits set during the 5th to 7th week of pegging grew at slower rates. Progressively smaller pod size for later set fruits occurred, presumably because older fruits were using photosynthate and less photosynthate was available for later set fruits while they were in the pod expansion phase.

Patel and Seshadri (1935) tagged flowers and reported that the Spanish peanut variety locally known in India as Gudiyattum required 95 days from planting or 60 days after flowering to produce mature nuts. Although tagging the flowers helped evaluate the age of the nuts, the authors indicated that the seeds from flowers which opened on the same day did not develop at the same rate. The gynophores from the flowers near the soil entered the earth and produced seeds earlier than those more distant.

There have been some investigations on fruit filling rate under shade on crops other than peanuts. Prine (1977) concluded that corn kernel weights tended to be lower when shading occurred during rapid kernel filling. But, he found an increase in soybean seed weight and a decrease in seed number when shading was applied during the pod enlargement stage (Prine, 1976). Shade during the seed filling stage reduced weight per seed.

Low light intensity during the milk and dough stages (3 weeks after 50% anthesis) on grain sorghum, reduced average seed weight (Pepper and Prine, 1972). Shade on rice during the reproductive stage decreased the kernel weight (Stansel et al., 1965). Earley et al. (1967) also found lower kernel weight of corn when 60% shade was applied during reproductive phase. On the other hand, increased light intensity had positive effects on grain weight of wheat (Spiertz, 1974), but decreased seed size of soybeans (Johnston et al., 1969). Shading severely reduced dry matter production, and less seriously reduced grain yield of wheat (Bremner, 1972). Seasonal light conditions have a pronounced effect on the rate of grain growth per ear of wheat. This is mainly by affecting the number of grains per ear (Sofield et al., 1974).

### Oil Content

In a review of plant fats in relation to environment and evolution, McNair (1945) noted that several factors influence fat production: stage of development, carbohydrate percentage, vegetative vigor, heredity, and environment. Ivanow (1912) showed that the percentage of oil increased in ripening flaxseed as the percentage of sugar decreased. In general, studies on the composition of maturing oil seeds have usually dealt only with the quantitative and qualitative aspects of the crude lipid fraction and in some cases with the soluble sugar. Markley (1947) pointed out, however, that moisture content, weight of seed, and percentage of other constituents in addition to histological and anatomical data are also necessary for proper interpretation of the synthesis of fatty acids in the growing plants. Patel and Seshadri (1935) noted that the percentage of oil, on a dry weight basis, increased very slowly at the beginning and ending of the developmental period.

Oil was synthesized rapidly between the 32nd and 46th day after flowering. Garner et al. (1914) found that under the conditions of their studies, climatic variations had more effect on size of seed and on oil content than did soil differences. It has been shown that the accumulation of oil in the seed proceeds throughout the greater portion of seed development and ripening. During the vegetative period, there is an accumulation of carbohydrates in the leaves and stems which is later utilized in the formation of the oil deposited in the seeds. The production of oil by the plant required favorable conditions for the accumulation of carbohydrate during the vegetative period and for the transformation of carbohydrate into oil during the second period.

McNair (1945) in an experiment on flaxseed concluded that slight shading increased the starch content, while the oil content was lowered. The quality of the oil was not influenced; but, with heavy shade, the iodine number was below normal.

There is a very sharp increase in oil percentage during the first few weeks after blossoming in soybeans, and then only a slow gain until near the end of ripening. During the final stage of ripening there is a decrease in both the size of seed and in oil content. In ripening seed, an increase in the percentage of oil is accompanied by a decrease in the carbohydrate percentage. Different varieties are not always influenced in the same manner by environment. Percentages of oil are influenced by both heredity and environment. Under practical conditions climate is a more potent factor than soil in modifying the oil content of seed.

Pickett (1950) found a very low lipid content in developing peanut shells. The lipid content of the starch-storing skin was also reported to be quite low (Rosen, 1958), and averaged less than 3% of the total testa dry weight.

Development of the lipid content of oil bearing seeds has been studied quite extensively. According to Bouffil (1951), Combes (1941) divided the development of lipid in seeds into four stages: (1) increase in seed size, with high sugar, protein, and ash but little lipid; (2) rapid increase in lipid to approach the maximum oil percentage; (3) oil percentage remains about steady at the maximum level; and (4) oil percentage declines. Evidence for these four stages are provided by reports on the lipid development of the peanut seed (Moriya et al., 1951; Pickett, 1950; and Shibuya, 1935) as well as of other oleaginous seeds (Eyre, 1931; Garner, 1914; and Hashad et al., 1956).

Bouffil (1951), however, maintained that stage 1 does not occur in the peanut. As evidence, he cited the work of Bouyer (1949) who reported finding about 30% oil in the seeds of fruits which were apparently about two weeks old. This indicated that oil synthesis had been proceeding continuously. Results similar to this were observed in Schenk's study where contents of 36 and 29%, respectively, were observed for the Spanish and Virginia seeds at three weeks.

### Carbohydrate Content

In the early stages of development, the shell of peanut was reported to contain a large amount of starch (Russell, 1931). However, a sugary syrup (Badami, 1935) or sugar (Waldron, 1919) has also been reported to fill the parenchymatous tissues of the shell. From the latter stage until maturity, however, the total sugar and starch of seeds remained constant (Pickett, 1950). He found that both sugar and starch of seed on a percentage dry weight basis decreased as seed developed; however, the percentage of total sugar increased slightly at maturity due to an increase in sucrose. The starch content of the seeds was quite high initially (Pickett, 1950; Prasad and Bosmas, 1956), but much of this was in the skins (Badami, 1935). The percentage of starch declined as the seeds began to expand rapidly (Pickett, 1950).

Archbold (1942) found in his experiments that shading barley ears reduced the size of the ears, but did not affect the number produced. Stem sugars were only slightly reduced. In the latter experiment, in which the stems of barley were shaded on three occasions, Archbold and Datta (1944) found that stem shading affected the plant organs. The shading treatment while sugar content was still increasing restricted both residual dry weight and sugar increases, but shading at the time of sugar maximum failed to induce polysaccharide breakdown or accelerate the rate of sugar loss. Since shaded or earless stems failed to make normal growth in the presence of increasing amounts of sugar, it appeared that utilization of sugar depends mainly upon factors other than carbohydrate supply.

There was a reduction of forage production of wheat and a reduction in water soluble carbohydrate content of both tall fescue and wheat as shade levels increased (Stritzke et al., 1976). Wardlaw et al. (1965) found that shading the ear reduced the movement of assimilates from the flag leaf to the shaded ear. In another experiment, they also found a redistribution of the assimilates from stem sugars, so shading may interfere with the accumulation of carbohydrate in the grains of wheat (Wardlaw and Porter, 1967).

Ulrich (1952) found that low light intensities or high day and night temperatures caused low sucrose concentrations in sugar beets. This was similar to corn in which light intensity was positively correlated with the carbohydrate contents of plants (Knipmeyer et al., 1962).

The carbohydrate constituents may offer promise as a means of characterizing the developmental stage, whereas the structural constituents of the shell appear to increase throughout development. In addition, a test of starch may be of value for precisely characterizing early developmental stages, although the nutritional status of the plant might affect this constituent greatly. There are other factors affecting oil percentage, total carbohydrate contents, and the quality of peanut seeds such as the soil moisture, fertilizer, and temperature.

The effects of low light intensity on carbohydrate accumulation in vegetation and in peanut fruits are not well-known. Flower initiation does not require light saturation; however, flowering and development are correlated with intensity and solar radiation (Gillier and Silvestre, 1969, and Hang An and McCloud, 1976) and therefore may be related to carbohydrate production.

If the peanut has a light requirement similar to those of the plants reviewed here, there should be certain periods during which light requirement is most critical in obtaining the highest yield and quality of peanut fruits.

# MATERIALS AND METHODS

During 1975 and 1976, Florunner (Norden et al., 1969) peanut was used in a two-year shading study under field conditions. The research was conducted in Arrendondo and Jonesville fine sand on the Agronomy farm at the University of Florida, Gainesville.

In the first experiment, the treatments were shaded for ten consecutive days at various stages of growth (Table 1). The shades consisted of two square wooden frames, 3.6 x 3.6 m, covered with 33 mm cloth strips spaced 11 mm apart. Total plot area was 3.6 x 7.2 m.

The same shade material was used in the second year experiment, when 3.6 x 3.6 m plots were shaded for 7, 14, and 21 consecutive days at the same growth stages as in the previous experiment, i.e., flowering, pegging, pod filling, and maturity (Table 2).

The shades were maintained approximately 50 cm above the soil surface. Measurements of light intensities in both experiments, under and above the shade, taken at mid-morning and mid-afternoon using a LI-170 Quantum/Radiometer/Photometer, showed that light intensity was reduced by 75% under the shade, i.e., 25% of the solar irradiance penetrated through the space between the cloth strips (Fig. 1).

The experimental area was hand-planted on April 22, 1975, and on the same day in 1976. In 1975, seeds were planted in a north-south row orientation with 91 cm row spacing and 15 cm spacing between plants in the row. Ten days after planting, similar aged plants in peat pots

Table 1. Schedule of shading periods, 1975.

| Shading period | Date | Plant age | Plant development |
|---|---|---|---|
| | | days | |
| C | Unshaded | | |
| F | June 6 to 16 | 44 to 54 | Flowering |
| G | June 24 to July 4 | 62 to 72 | Pegging |
| P | July 15 to 25 | 83 to 93 | Pod filling |
| M | Aug. 5 to 15 | 104 to 114 | Maturing |

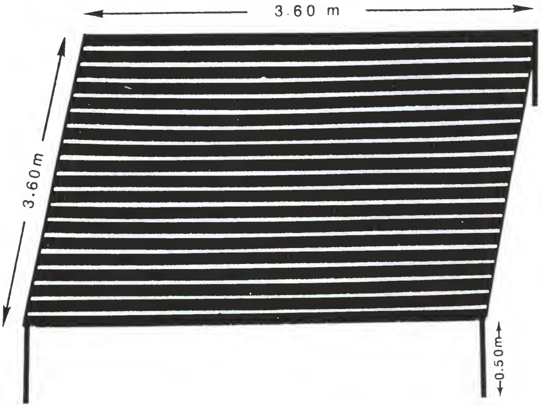

Fig. 1. Portable shade.

Table 2. Schedule of shading periods, 1976.

| Treatment | Date | Shading period plant age | Plant development |
|---|---|---|---|
| | | days | |
| C | Unshaded | | |
| $F_7$ | June 3 to 10 | 41 to 48 | Flowering |
| $F_{14}$ | June 3 to 17 | 41 to 55 | |
| $F_{21}$ | June 3 to 24 | 41 to 62 | |
| $G_7$ | June 24 to July 1 | 62 to 69 | Pegging |
| $G_{14}$ | June 24 to July 8 | 62 to 76 | |
| $G_{21}$ | June 24 to July 15 | 62 to 83 | |
| $P_7$ | July 15 to July 22 | 83 to 90 | Pod filling |
| $P_{14}$ | July 15 to July 29 | 83 to 97 | |
| $P_{21}$ | July 15 to Aug. 5 | 83 to 104 | |
| $M_7$ | Aug. 5 to Aug. 12 | 104 to 111 | Maturing |
| $M_{14}$ | Aug. 5 to Aug. 19 | 104 to 118 | |
| $M_{21}$ | Aug. 5 to Aug. 26 | 104 to 125 | |

were transplanted into any missing hills. The resulting population was 7.33 plants per $m^2$.

In the 1976 experiment, nearly equidistant plant spacing was used (25.4 cm by 30.5 cm). Three seeds were placed per hill and after emergence, thinned to one plant to insure a uniform stand. This spacing resulted in 12.9 plants per $m^2$, which is within the range of maximum yield for Florunner peanuts.[1]

## Land Preparation

Fertilizers and pesticides were applied to insure a good stand and healthy plants. Table 3 indicates the time and method of application of fertilizer and pesticides.

In the first experiment, a 5 x 5 Latin square was used to study four shading periods. For the second year, a factorial design was used with two levels of light intensity, i.e., 100% and 25%, and four different stages of growth--flowering (F), pegging (G), pod filling (P), and maturity (M). Shade was maintained 7, 14, and 21 consecutive days in the second experiment instead of a 10-day period as the first year. The field layout of these treatments in both experiments was completely random within each of four replications.

## Sampling for Yield Components

Observations were made during the growing season of the morphological responses to the treatments, as well as the incidence of insects and diseases. The sampling schedule in both experiments is listed in Tables 4 and 5.

In 1976, 30 plant samples for measuring total biomass were taken from each plot after each shade period, control plots were sampled at

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[1] Malagamba, J. P. 1976. Ph.D. Dissertation, University of Florida.

Table 3. Fertilizers and pesticides used in the peanut shading experiments, 1975 and 1976.

| | Products | Rate per ha | Application |
|---|---|---|---|
| **1975 Experiment** | | | |
| Planting Date: Apr. 22, 1975<br>Harvesting Date: Sept. 4, 1975 | | | |
| Fertilizers | 2-10-10* | 780.0 kg | Disked in April 1 |
| | Gypsum (67.2%) | 840.0 kg | Machine broadcast on June 10 |
| Herbicides | Lasso (43% a.i.) | 7.0 liter | At cracking stage April 25 |
| | Dyanap (33.8% a.i.) | 14.0 liter | |
| Insecticides | Chlordane (40% a.i.) | 7.0 kg | At disking, mixed with fertilizer |
| | Sevin (80% a.i.) | 1.7 kg | Sprayed at 10-day intervals |
| Fungicides | Bravo (54% a.i.) | 1.0 kg | Sprayed at 10-day intervals |
| **1976 Experiment** | | | |
| Planting Date: Apr. 22, 1976<br>Harvesting Date: Sept. 14, 1976 | | | |
| Fertilizers | 2-10-10* | 560.0 kg | Disked in April 2 |
| | Gypsum (67.2%) | 840.0 kg | At flowering stage on June 6 |
| Herbicides | Balan (2.5% a.i.) | 7.0 liter | One week before planting (April 15) |
| | Vernan (83.8%) | 2.3 liter | |
| | Lasso (43% a.i.) | 7.0 liter | At cracking (April 29) |
| | Dinitro (80% a.i.) | 14.0 liter | |
| Insecticides | Chlordane (40% a.i.) | 7.0 kg | At disking (April 2) |
| | Sevin (80% a.i.) | 1.7 kg | Applied 10 to 15 day intervals |
| | Lannate (52.8% a.i.) | 3.5 liter | Applied two occasions |
| Fungicides | Bravo (54% a.i.) | 1.0 kg | Applied 10-15 day intervals |

* 2-10-10 fertilizer mix containing Diammonium phosphate, Potassium Chloride, Triple superphosphate, and 0.9% Chlordane.

Table 4. Sampling schedule, 1975.

| Sampling number | Date | Plant age | Sample plots |
|---|---|---|---|
| | | days | |
| 1 | May 16 | 24 | C |
| 2 | May 23 | 31 | C |
| 3 | June 6 | 44 | C F |
| 4 | June 16 | 54 | C F* |
| 5 | June 24 | 62 | C F G |
| 6 | July 4 | 72 | C F G* |
| 7 | July 15 | 83 | C F G P |
| 8 | July 25 | 93 | C F G P* |
| 9 | Aug. 5 | 104 | C F G P M |
| 10 | Aug. 15 | 114 | C F G P M* |
| 11 | Sept. 3 | 133 | C F G P M |
| Final harvest | Sept. 5 | 135 | C F G P M |

* Sampled immediately after treatment.

Table 5. Sampling schedule, 1976.

| Sampling number | Date | Plant age | Harvested plots |
|---|---|---|---|
| | | days | |
| 1 | June 3 | 41 | C |
| 2 | June 10 | 48 | C and $F_7$ |
| 3 | June 17 | 55 | C and $F_{14}$ |
| 4 | June 24 | 62 | C and $F_{21}$ |
| 5 | July 1 | 69 | C and $G_7$ |
| 6 | July 8 | 76 | C and $G_{14}$ |
| 7 | July 15 | 83 | C and $G_{21}$ |
| 8 | July 22 | 90 | C and $P_7$ |
| 9 | July 29 | 97 | C and $P_{14}$ |
| 10 | Aug. 5 | 104 | C and $P_{21}$ |
| 11 | Aug. 12 | 111 | C and $M_7$ |
| 12 | Aug. 19 | 118 | C and $M_{14}$ |
| 13 | Aug. 26 | 125 | C and $M_{21}$ |
| 14 | Sept. 14 | 145 | Final harvest (All plots) |

the same time (Fig. 2). Ten plants of each sample were separated to analyze the development of vegetative and reproductive components of the plant biomass. The root system was removed, and flowers per plant of the ten plant subsample were recorded. Vegetative components were dried in a forced draft oven at 60 C until constant weight was obtained. The number and weight of fruits, in five maturity stages, were determined as suggested by Gregory et al. (1951, 1973)(Table 6).

The remaining 20 plants from the samples were dried and weighed to obtain additional data for total dry biomass.

For final yield comparisons, four replications of all treatments were harvested (Fig. 2). From each plot 30 plants were sampled, mechanically picked, and placed in a forced draft oven at 60 C until dry.

Dry weights of all plant parts were recorded after each sampling. Mature pods of each harvest were weighed and graded on sizing screens into the following fruit diameter categories:

I Very small: less than 10.7 mm
II Small: from 10.7 mm to 13.5 mm
III Medium: from 13.5 mm to 14.3 mm
IV Large: greater than 14.3 mm

The seeds were also sized using the conventional types of screens for runner market type peanut grading. Seed size in this classification was:

I Very small: less than 6 mm x 19 mm
II Small: from 6 mm x 19 mm to 6.4 mm x 19 mm
III Medium: from 6.4 mm x 19 mm to 8.5 mm x 19 mm
IV Large: greater than 8.5 mm x 19 mm

Table 6. Peg and pod categories.

| Category | Description |
|---|---|
| 1 | Aerial pegs |
| 2 | Pegs inserted in the soil, but no ovary swelling |
| 3 | Slightly swollen ovaries, but smaller than fully expanded pods |
| 4 | Full-sized pods that shrivel upon drying |
| 5 | Full-sized pods that do not shrivel on drying, "mature pods" (mature fruits) |

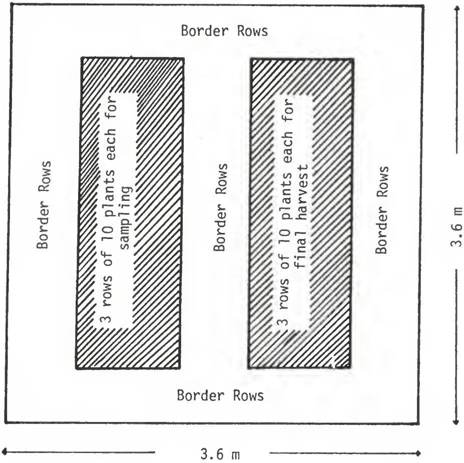
Border Rows
3 rows of 10 plants each for sampling
3 rows of 10 plants each for final harvest
Border Rows
Border Rows
Border Rows
Border Rows
3.6 m
3.6 m

Fig. 2. Experimental plot. Shaded areas were subjected to sampling and harvesting at the end of the season.

Weight and number of fruits and seeds in each category were recorded to calculate the average fruit and seed weight, after correcting for moisture content.

## Fruit Growth Rate

One of the twelve treatments of shading was chosen to study the pod growth rate, i.e., 21-day shading during pod filling period—$P_{21}$. Recently penetrated pegs of eight shaded and eight control plants of each replication were tagged weekly starting June 7, 1976 (45-day old plants). Different colored 18 mm wound surgical clips were used each week to mark the age of pegs. One plant from each treatment plot was sampled every 11 days beginning July 3 (71-day old plants). The schedule of tagging and harvesting for fruit filling rate is listed in Table 7.

Fruits of each plant were excised immediately after digging and dried in separate paper bags according to fruit age. For uniformity, only undamaged, two-seeded, two-loculed fruits were included in the analysis. After recording the dry weight of fruits and seeds and the color of the inner pericarp, the samples were stored for carbohydrate analysis. For each weekly set of fruits, the rate of fruit growth and seed growth were computed from the respective dry weights versus fruit age in days. The color of the inner wall was observed to estimate the stage of maturity.

Linear regression models were used to compute the rates of fruit and seed growth as dry weight gain per day per fruit or per two seeds.

## Carbohydrate Analysis

Carbohydrate analysis was performed on fruits having dry weights close to the predicted weights (linear regression models) for given fruit ages.

Table 7. Fruit growth rate, schedule of tagging and harvesting.

| Color | Tagging | | Harvesting | |
|---|---|---|---|---|
| | Date | Plant age | Date | Plant age |
| | | days | | days |
| Y | June 7 | 45 | July 3 | 71 |
| B | June 14 | 52 | July 14 | 82 |
| M | June 21 | 59 | July 25 | 93 |
| R | June 28 | 66 | Aug. 5 | 104 |
| W | July 5 | 73 | Aug. 16 | 115 |
| O | July 12 | 80 | Aug. 26 | 125 |
| | | | Sept. 14 | 145 |

The seeds and respective shells were weighed and kept separately. The seed skins were left on the seed during chemical analysis, because of the difficulty in separating the testae from very young seed. The shells were ground thoroughly after which a subsample was weighed prior to sugar extraction with 80% ethanol. Seeds and testae were ground in mortar and pestle using a circular motion.

## Oil Extraction by Petroleum Ether

Scheme of oil, sugar, and starch extraction from peanut seeds is shown in Fig. 3. Weighed seeds were ground in a mortar to which 5 ml of petroleum ether were added to dissolve the oil from the seeds. After settlingfor a few minutes, the petroleum ether-oil mixture was pipetted off. This step was repeated five times or until the petroleum ether was clear. The petroleum ether-oil mixture was combined into a weighed beaker and evaporated in a hood at room temperature overnight, followed by four hours in a 60 C oven. The weights of oil and defatted seed were recorded. The percentage of oil in seed was computed from these weights. Defatted seed was stored for sugar extraction.

## Sugar and Starch Extraction from Peanut Seeds

Sugar in the seeds was extracted three times with 80% ethanol (Fig. 3). The Shaffer-Somogyi (1933) reagent was used to determine the reducing and total sugar (sucrose being inverted with invertase), (Appendix 4-A). Starch was hydrolyzed from the 80% ethanol insoluble residue by incubation at 41 C with amyloglucosidase in acetate buffer (Appendix 7-A, Fig. 3).

Reducing sugars, sucrose, total sugars, and starch were reported as glucose equivalent as a percentage of dry weight of seeds or shells.

## Sugar and Starch Extraction from Peanut Shells

Sugar was extracted from the shells by three successive extractions with 80% ethanol (Fig. 4). The shell residue was then ground in acetate buffer with conical glass grinders to insure complete extraction of starch from the coarse shell tissue (Appendix 7-2).

After extraction, appropriate aliquots of sugar solution and starch hydrolyzate were analyzed for sugars as above (Appendices 5-A, 6-A, and 7-A).

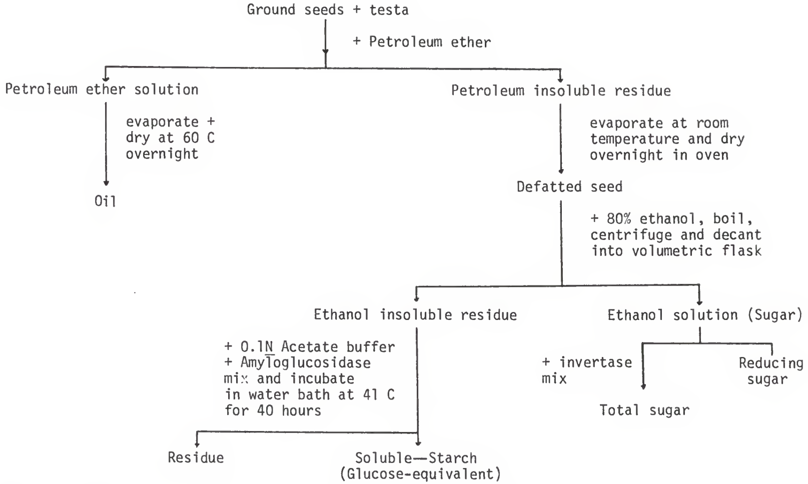
Ground seeds + testa
+ Petroleum ether
Petroleum ether solution
evaporate + dry at 60 C overnight
Oil
Petroleum insoluble residue
evaporate at room temperature and dry overnight in oven
Defatted seed
+ 80% ethanol, boil, centrifuge and decant into volumetric flask
Ethanol insoluble residue
+ 0.1N Acetate buffer
+ Amyloglucosidase mix and incubate in water bath at 41 C for 40 hours
Residue
Soluble—Starch (Glucose-equivalent)
Ethanol solution (Sugar)
+ invertase mix
Total sugar
Reducing sugar

Fig. 3. Scheme of oil, sugar, and starch extraction from peanut seeds.

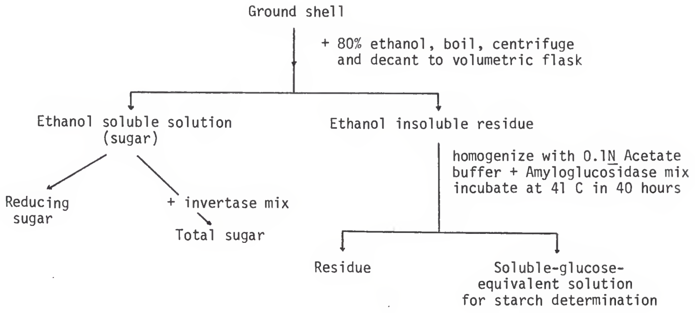
Ground shell
+ 80% ethanol, boil, centrifuge and decant to volumetric flask
Ethanol soluble solution (sugar)
Ethanol insoluble residue
Reducing sugar
+ invertase mix
Total sugar
homogenize with 0.1N Acetate buffer + Amyloglucosidase mix incubate at 41 C in 40 hours
Residue
Soluble-glucose-equivalent solution for starch determination

Fig. 4. Scheme of sugar and starch extraction from peanut shells.

# RESULTS AND DISCUSSION

## 1975 and 1976 Weather

The mean air and soil temperatures of the two years, 1975 and 1976, varied from 20 to 29 C and appeared optimum for growth and development of peanut. There were only small differences in temperature and solar radiation between the two growing seasons. Rainfall was well-distributed during the six-month growing season. It varied mostly from 100 to 200 mm per month. Solar radiation was between 400 and 500 cal/cm$^2$/day. The favorable temperature and rainfall conditions throughout the season likely reduced the temperature effect of the shades. Temperature, solar radiation, and rainfall of the 1975 and 1976 seasons are listed in Table 8. The accumulation of solar energy during the shading period of the first and the second year experiments is shown in Table 9.

An air temperature difference of 1 C in the plant canopy was measured between the shaded and unshaded canopies, along with 1 to 1.5 C between the shaded and unshaded treatments at the soil surface, and a 2 C difference at the depth of 7.5 cm in the soil. Although it is known that peanut growth, flowering, and fruit set are influenced by temperature (Bolhuis, 1959), the effect of 1 C decrease in air temperature is probably minimal compared to the effect of shading.

## 1975 Experiment

The effects of shading on pod and peg development and on yield components of peanuts during the 1975 experiment are summarized in Tables 10, 11, and 12.

Table 8. Temperature, rainfall, and solar radiation during growing season.

| Month | Temperature (C) | | | | | | Total Rainfall | Avg. Solar Radiation |
|---|---|---|---|---|---|---|---|---|
| | Air | | | Soil | | | | |
| | Avg. Max. | Avg. Min. | Avg. Mean | Avg. Max. | Avg. Min. | Avg. Mean | | |
| | | | | | | | mm | cal/cm$^2$/day |
| | | | | 1975 | | | | |
| Apr/75 | 28.6 | 14.1 | 21.4 | 23.1 | 21.4 | 22.2 | 56 | 409 |
| May/75 | 32.1 | 18.8 | 25.6 | 28.1 | 25.5 | 26.8 | 127 | 428 |
| June/75 | 32.6 | 19.7 | 27.1 | 30.4 | 28.5 | 29.4 | 123 | 441 |
| July/75 | 31.3 | 21.7 | 26.6 | 29.7 | 28.4 | 29.0 | 163 | 439 |
| Aug/75 | 33.4 | 21.6 | 27.6 | 30.0 | 29.7 | 29.8 | 112 | 536 |
| Sept/75 | 31.4 | 20.8 | 26.3 | 29.0 | 28.0 | 28.5 | 318 | 459 |
| | | | | 1976 | | | | |
| Apr/76 | 27.9 | 13.0 | 20.4 | 22.8 | 21.3 | 22.0 | 81 | 517 |
| May/76 | 29.4 | 17.3 | 23.3 | 25.7 | 23.8 | 24.7 | 162 | 468 |
| June/76 | 31.2 | 19.9 | 25.5 | 28.2 | 25.8 | 27.0 | 289 | 475 |
| July/76 | 33.6 | 21.7 | 27.6 | 30.8 | 28.2 | 29.5 | 117 | 486 |
| Aug/76 | 32.8 | 21.7 | 27.2 | 29.9 | 28.0 | 28.9 | 72 | 452 |
| Sept/76 | 31.6 | 20.1 | 25.8 | 28.5 | 26.8 | 27.6 | 136 | 403 |

Table 9. Total solar radiation during shading periods.

| Shading Period | Solar Radiation |
|---|---|
| | cal/cm$^2$/period |
| 1975 | |
| June 5 to 15 | 4303 |
| June 25 to July 3 | 3997 |
| July 14 to 24 | 5369 |
| Aug. 4 to 14 | 5535 |
| 1976 | |
| June 3 to 10 | 3352 |
| June 3 to 17 | 6895 |
| June 3 to 24 | 9648 |
| June 24 to July 1 | 3626 |
| June 24 to July 8 | 6785 |
| June 24 to July 15 | 10140 |
| July 15 to July 22 | 3480 |
| July 15 to July 29 | 7207 |
| July 15 to Aug. 5 | 10052 |
| Aug. 5 to 12 | 3473 |
| Aug. 5 to 19 | 6662 |
| Aug. 5 to 26 | 9589 |

Table 10. Effects of shading at different stages of growth on average pod weight and percentage of pegs forming pods at 72, 93, and 114 days, 1975.

| Age | Trt[1] | Peg + Pod | Harvestable fruit | Mature Fruit |  | Fruit weight |
|---|---|---|---|---|---|---|
|  |  |  |  | % | mg/fruit |  |
|  |  | No./$m^2$ | No./$m^2$ |  |  | g/$m^2$ |
| 72 | C | 960a[2] | 59a | 5.5a | 521a | 28.6a |
|  | G | 623b | 22a | 3.4a | 583a | 13.2a |
| 93 | C | 1180a | 242a | 21.0a | 866b | 210.0a |
|  | P | 1085a | 168b | 15.5a | 941a | 158.0a |
| 114 | C | 1275a | 381a | 29.3a | 1223b | 468.0a |
|  | M | 1224a | 366a | 32.0a | 1317a | 477.0a |

[1] C = control unshaded treatment; G = shading from days 62 to 72; P = shading from days 83 to 93; M = shading from days 104 to 114; F = shading from days 44 to 54.

[2] Treatment comparisons in the same column not followed by the same letter are significantly different at 5% level according to Duncan's multiple range test.

Table 11. Top dry weight and yield components of peanuts at 133 days, 1975.

| Trt[1] | Peg + Pod | Harvestable fruit | Plant top weight | Harvestable fruit | Mature fruit | |
|---|---|---|---|---|---|---|
| | | | | | % | mg/fruit |
| | No./$m^2$ | No./$m^2$ | g/$m^2$ | g/$m^2$ | | |
| C | 1444a[2] | 623a | 598a | 713a | 43.4a | 1140a |
| F | 909c | 469b | 515a | 570b | 52.0a | 1233a |
| G | 982bc | 498ab | 460a | 568b | 51.6a | 1150a |
| P | 1092abc | 447b | 470a | 491b | 41.2a | 1106a |
| M | 1431ab | 528ab | 572a | 624ab | 41.7a | 1189a |

[1] Each value is the average of 5 replications of 2 plants each.

[2] Values in a column not followed by the same letter are significantly different at 5% level according to Duncan's multiple range test.

Table 12. Effects of low light intensity on pod yield, extra large seeds, sound mature seeds, shriveled seeds, and 100-seed weight.

| Treatment | Yield | ELS | SMS | SHRS | 100-WT |
|---|---|---|---|---|---|
| | kg/ha | % | % | % | g |
| C | 5450a | 40.3bc | 74.5a | 2.0ab | 58.9a |
| F | 5370a | 42.9ab | 74.5a | 1.8ab | 58.4a |
| G | 5250a | 45.2a | 75.5a | 1.5b | 59.6a |
| P | 5030a | 37.4c | 73.6a | 2.8a | 57.5a |
| M | 5350a | 44.9a | 72.9a | 3.0a | 60.0a |

Each value is the average of 5 replications.

Values in a column not followed by the same letter are significantly different at 5% level according to Duncan's multiple range test.

ELS = extra large seeds; SMS = sound mature seeds; SHRS = shriveled seeds; and 100-WT = 100-seed weight.

Flowering began at 31 days after planting, with the peak flowering period extending from days 45 to 75 in the unshaded check plots. After 80 days, flowering became very sparse and sporadic. One week after the first flower occurred, peg formation began and continued until no more flowers opened. The first full sized fruit was obtained at 69 days after planting. During the middle of the growing season, four stages of the plant cycle (flowering, pegging, pod formation, and pod maturation) occurred at the same time on the same plant.

In 1975, shade was applied for 10-day periods at four stages of growth, i.e., flowering, pegging, pod filling, and maturity. Shade caused the following morphological effects on plant development: higher chlorophyll content per unit leaf fresh weight, taller plants, and thinner leaves (Hang An and McCloud, 1976).

Shading treatments that spanned the maximum flowering period markedly reduced the number of flowers. Ovules of the flowers which were present on the plants when the shades were applied, did not form pegs. The delayed recovery of flowering after the removal of shade at this stage suggested that flowering does not have priority for photosynthate over filling pods.

Shade at early reproductive periods had a greater effect on the number and dry weight of pegs and pods (Tables 10 and 11). Shading during the pod filling stage reduced the number of harvestable fruits by 26% at the time of shade removal (Table 10), and after that period the plant did not have enough time to recover from such physiological stress. Shade reduced yield, but showed no significant effects on the final yield at 135 days after planting (Table 12). The lowest yield of fruits was observed in the plots receiving low light intensity at the pod filling stage (from days 83 to 93). The second lowest resulted from shade at the pegging stage (treatment G, days 62 to 72).

There was a difference between shaded and unshaded plants on the percentage of pegs forming fruits (Table 11). When shading caused fewer total pegs and fruits per plant (as for treatments F and G), there was a tendency for a higher percentage of fruits to mature (Table 11), and a higher percentage of sound mature seeds (Table 12). The lower number of harvestable fruits formed in treatments F and G (Shaded from days 44 to 54, and 62 to 72) was compensated for by an increase in average weight per fruit and more complete seed filling (higher percentage of sound mature seeds).

Plants shaded during the early season may have enough time to recover from the stress, in contrast to the plots receiving low light intensity near the end of the growing season (treatments P and M—days 83 to 93, and 104 to 114) while shading for a 10-day period caused no significant effects on yield, it did increase the percentage of shriveled seeds by 40 and 50%, respectively, particularly during pod filling and maturity periods (Table 12). The highest percentage of shriveled seeds was observed on plots receiving low light intensity during maturing stage (3%).

Plant top dry weight did not change significantly, but tended to be lower for treatments G and P (from days 62 to 72, and 83 to 93).

## 1976 Experiment

### Total Biomass, Vegetative, and Reproductive Growth

Rates of dry weight accumulation and fruit growth were calculated from weekly samples and expressed as $g/m^2/day$. The average partitioning factor during four successive, three-week periods was calculated after correcting for fruit composition; for fruit growth, 1.65[1] times as much photosynthate is used as for vegetative growth. Partitioning factor was calculated from the following equation:

$$\frac{\text{Rate of reproductive growth} \times 1.65}{\text{Rate of corrected total biomass}} \times 100$$

Three different lengths of shading period, 7, 14, and 21 days, were applied at four different stages of growth. The relationship between total biomass, vegetative, and reproductive growth under low and normal light intensity is shown in Figs. 5, 6, and 7. Under shade conditions, vegetative and reproductive growth appeared to stabilize at much lower rates and continued as long as the shade period lasted. The relative effect on reproductive growth depended on the stage of plant growth (Table 13). Most of the energy received from sunlight during the flowering stage was used to produce vegetative growth (branches, leaves). During this stage, the rates of dry weight accumulation of the unshaded check plots were 11.5, 10.8, and 0.5 $g\ m^{-2}\ day^{-1}$ for total biomass, vegetative, and reproductive parts, respectively. Shade during the flowering stage caused 53 and 64% reductions in vegetative and reproductive growth rates, respectively. Vegetative growth was predominant and was reduced less than reproductive growth by shade at this stage (treatments $F_7$, $F_{14}$, and $F_{21}$), (Table 13).

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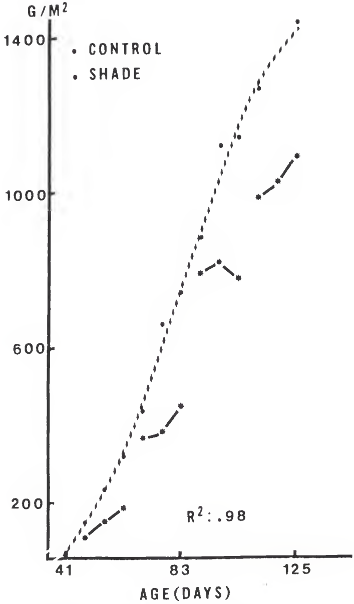
[1] McGraw, R. L. 1977. MS Thesis, University of Florida.

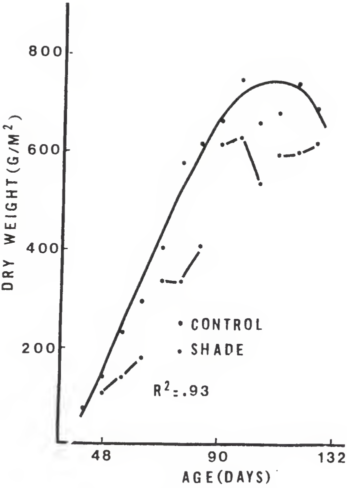


MODEL: $Y = 576.694 - 36.253X + 0.701X^2 - 0.00286X^3$

Y: predicted weight of total biomass of peanut plant (g/m$^2$)

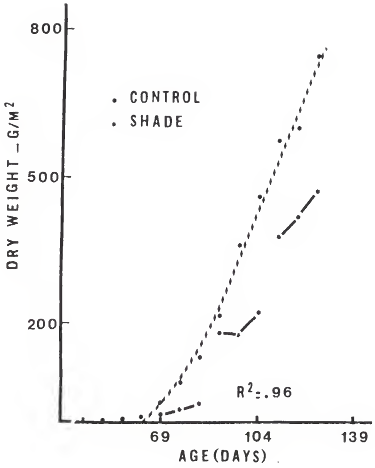
X: plant age (days).

Fig. 5. Relationship between total biomass production of control and treated plants to plant age.



MODEL: $Y = -331.788 + 2.543X + 0.225X^2 - 0.00144X^3$
Y: predicted weight of vegetative growth of peanut plant (g/m$^2$).
X: plant age (days).

Fig. 6. Relationship of vegetative growth of peanut plant to plant age.



MODEL: $Y = 908.483 - 38.796X + 0.4765X^2 - 0.001416X^3$
Y: predicted weight of reproductive parts of peanut plant ($g/m^2$).
X: plant age (days).

Fig. 7. Regression line presenting experimental data and predicted reproductive growth of shaded and unshaded plants.

Table 13. Effects of shade on vegetative and reproductive growth rates and partitioning factor at four stages of peanut growth, 1976.

| Stage | Trt[a] | Vegetative | | Reproductive | | Corrected growth rate[b] | Corrected Biomass | | Partition to Reproduction | Change Partition |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Growth rate | Reduction | Growth rate | Reduction | | Growth rate[c] | Reduction | | |
| | | g/m$^2$/day | % | g/m$^2$/day | % | g/m$^2$/day | g/m$^2$/day | % | % | % |
| F | C | 10.79 | | 0.45 | | 0.74 | 11.53 | | 6.4 | |
| | S | 5.01 | 53.4 | 0.16 | 63.6 | 0.27 | 5.28 | 54.2 | 5.1 | - 20.3 |
| G | C | 16.19 | | 5.69 | | 9.39 | 25.58 | | 36.7 | |
| | S | 4.79 | 70.4 | 1.21 | 78.7 | 2.00 | 6.79 | 73.5 | 29.5 | - 19.6 |
| P | C | 3.15 | | 16.01 | | 26.42 | 29.57 | | 89.4 | |
| | S | - 3.19 | 201.4 | 3.81 | 76.2 | 6.29 | 3.09 | 89.5 | 203.1 | + 127.2 |
| M | C | 1.79 | | 12.66 | | 20.88 | 22.67 | | 92.1 | |
| | S | 1.51 | 15.9 | 6.51 | 48.6 | 10.74 | 12.24 | 46.0 | 87.7 | - 4.8 |

[a] F, G, P, and M are presented for flowering, pegging, pod filling, and maturity stages, respectively; C = control plants; S = shaded plants.

[b] Corrected for fruit composition.

[c] Corrected biomass growth rate is the sum of vegetative growth rate and reproductive growth rate corrected for fruit composition.

Crop growth rate was greater during the pegging stage. The shade-induced reduction in vegetative, reproductive, and total biomass growth was 70, 79, and 74%, respectively, for shade during the pegging stage. During pegging period, the shaded plants contributed only 1.2 $g/m^2/day$ and 4.8 $g/m^2/day$ to the reproductive and vegetative growth, respectively. Although biomass production was reduced 74% by shade, the partitioning factor was near 30%, and the degree of partitioning to fruits was reduced by one-fifth.

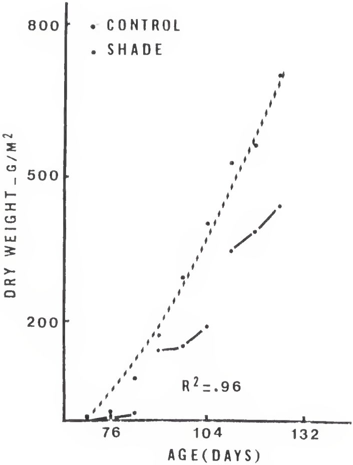
Maximum growth rate was found during pod filling stage during which most of the photosynthetic production contributed to reproductive growth. For controls, the growth rates were 16.0 $g/m^2/day$ for reproductive growth, and 3.1 $g/m^2/day$ for the vegetative production. Partitioning to fruits was a reasonable 89% for control plants at this stage. Under shaded conditions, none of the photosynthate was used for vegetative growth. In fact, a negative vegetative growth rate was calculated, -3.2 $g/m^2/day$. The rate of reproductive growth in shade was 3.8 $g/m^2/day$, and was reduced 76% compared to the unshaded plants. The calculated negative vegetative growth resulted in very high "apparent" partitioning which was increased by shade at pod filling stage (treatments $P_7$, $P_{14}$, and $P_{21}$). The drastic effects of shade on vegetative growth and partitioning during the pod filling stage are consistent with this stage being the most sensitive to shade in terms of reduction in final yield.

The reduction caused by shading during maturation (treatments $M_7$, $M_{14}$, and $M_{21}$) was less on vegetative, reproductive, and total biomass production 16, 49, and 46%, respectively. During this stage, vegetative growth of controls was low, about 1.8 $g/m^2/day$, while reproductive growth rate continued high, near 12.7 $g/m^2/day$. Nearly 92% of the photosynthate was partitioned to fruits at this stage. Shade did not affect partitioning at this stage. Partitioning was increased sharply from flowering to pegging to the pod filling stage and remained high during the maturity stage. The maximum growth rate of reproductive structures occurred at pod fill and maturing stages, whereas the maximum growth rate for vegetative growth had occurred around pegging stage (from days 62 to 83).

Averaged over all stages, 75% reduction of light intensity decreased the growth rate of vegetative parts by 85%, the reproductive growth rate by 67%, and the total biomass growth rate by 66%. Partitioning factor was decreased by one-fifth during shade at the first two reproductive stages, but it increased during the period of pod filling.

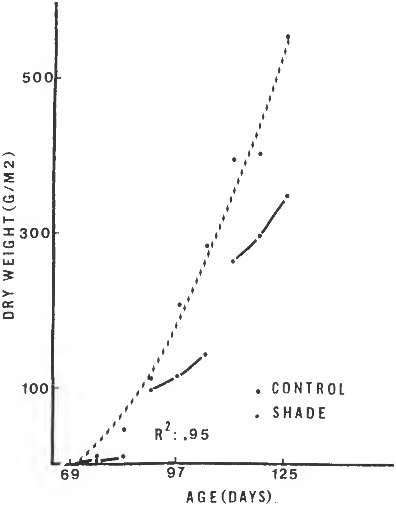
Figures 8 and 9 present the relationship of fruit and seed yield over time for the control and shaded plants of different treatments. A decrease in fruit and seed weight was observed under shading stress. The difference between the rate of fruit growth on unshaded plants and shaded plants was maximum when 21-day shade had been applied.

Data on top growth, root growth, and reproductive growth are shown in Tables 14, 15, 16, and 17. Root growth was lower when plants were shaded during the period of maximum vegetative growth (treatments F and G), which is in agreement with Pendleton (1965). A significant reduction in root weight was found for all three lengths of shading during the first two stages of plant growth. During the period when the plants contributed most of their energy to reproductive growth, the reduction in root weight was minimal (days 83 until digging). No significant difference in root weight was found with the treatments P and M. While



MODEL: $Y = 883.956 - 36.0247X + 0.4132X^2 - 0.00109X^3$
Y: predicted yield of peanut fruit (g/m$^2$).
X: plant age (days).

Fig. 8. Fruit yield of unshaded and shaded peanut plants versus plant age.



MODEL: $Y = 525.294 - 20.415X + 0.212X^2 - 0.000374X^3$

Y: predicted seed yield (g/$m^2$)

X: plant age (days)

Fig. 9. Seed yield of unshaded and shaded peanut plants versus plant age.

the reason for that is unknown, a possible explanation is that no further development of the root system occurred after this stage, so no shade effect was encountered. The longer the shading period the greater the reduction in dry weight of all plant parts.

## Yield Components

Flowers, pegs, and fruits. The effect of shading for seven days was less during the maximum vegetative growth. In that period, the plant used energy for development of new branches and produced more leaves which were probably in excess at later stages and of minimal importance. Shade for seven days did not cause much effect on number of young pegs or on dry weight production in plant parts. Flowers and pegs of stages 1 and 2 tended to be lower in both number and dry weight under low light conditions. Data on flowers, pegs, and fruits of the shaded and unshaded plants during flowering stage are listed in Table 14. Four pegs of category 3 (swollen pegs) were found in the check plots. Low light intensity at this stage reduced the formation on new pegs from one peg and pod category to the next.

During two weeks shading at flowering stage (treatment $F_{14}$, from days 41 to 55), the number of flowers and newly formed pegs (category 2) were reduced, 45 and 30%, respectively. Flower number was drastically reduced after 21-day shading to less than 25% of the normal plant (Table 14). The longer the shade period the greater the reduction in reproductive weight. Older pegs had priority in using photosynthate over the younger ones. The 75% reduction in sunlight caused no significant difference in number of pegs and pods of stages 3 and 4; however, the average weight of these pegs and pods was decreased significantly. The low light intensity undoubtedly reduced the level of photosynthate,

Table 14. Effects of different shading treatments during the flowering stage on flowers, peg and pod development, and their dry weight.

| Measured responses | Age of plant in days | | | | | |
|---|---|---|---|---|---|---|
| | 48 | | 55 | | 62 | |
| | Treatment | | | | | |
| | C | F$_7$ | C | F$_{14}$ | C | F$_{21}$ |
| Flower (No./m$^2$) 1/ | 33 | 21 | 36 | 20 | 81$^a$ | 17$^b$ |
| Peg & Pod (No./m$^2$) 1/ | | | | | | |
| 1 | 21 | 9 | 92$^a$ | 52$^b$ | 105$^a$ | 72$^b$ |
| 2 | 11 | 11 | 94$^a$ | 66$^b$ | 222$^a$ | 138$^b$ |
| 3 | 4$^a$ | 0$^b$ | 14 | 8 | 84 | 52 |
| 4 | 0 | 0 | 0 | 0 | 11 | 2 |
| Peg & Pod Wt. (g/m$^2$) 1/ | | | | | | |
| 1 | 0.3 | 0.3 | 0.4 | 0.2 | 0.6$^a$ | 0.4$^b$ |
| 2 | 0.4 | 0.4 | 1.2$^a$ | 0.5$^b$ | 3.5$^a$ | 1.9$^b$ |
| 3 | 0.3 | 0.1 | 1.3$^a$ | 0.2$^b$ | 2.8$^a$ | 1.1$^b$ |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0$^a$ | 0.4$^b$ |
| Top Wt. (g/m$^2$) 2/ | 139.7$^a$ | 104.0$^b$ | 224.0$^a$ | 135.6$^b$ | 293.3$^a$ | 175.9$^b$ |
| Root Wt. (g/m$^2$) 2/ | 4.5$^a$ | 3.1$^b$ | 7.2$^a$ | 4.1$^b$ | 9.3$^a$ | 4.4$^b$ |
| Repr. Wt. (g/m$^2$) 2/ | 1.0$^a$ | 0.7$^b$ | 2.8$^a$ | 0.9$^b$ | 9.9$^a$ | 3.8$^b$ |

1/ Each value is the average of 4 replications of 10 plants each.

2/ These values are the average of 4 replications of 30 plants each.

Values of the same row of the same age not followed by the same letter are significantly different at 5% level.

reduced N-compounds and other essential metabolites needed for flower and peg development and growth. Shading during the maximum stage of flowering may have caused the abortion of embryos of the first flowers. Under normal light intensity, these would produce mature fruits at harvest, i.e., about 70% (Shear and Miller, 1955).

Residual shading effects may also persist for a time in the treated plots as observed in the 1975 experiment. The recovery of flowering, peg formation and vegetative growth of shaded plants was slow after the removal of shades. If flowering and vegetative growth are considered as competing sinks during this period, vegetative growth is more competitive than peg development during the flowering period.

The highest rate of flowering was found around day 69 (early pegging stage, treatment G). Flowering was reduced 90% by shade at this stage (treatment $G_7$, from days 62 to 69), (Table 15). Flowering ceased after two or three weeks of shade (treatment $G_{14}$, from days 62 to 76, and treatment $G_{21}$, from days 62 to 83). The number and dry weight of pegs and pods were greatly reduced on plants shaded and stabilized at 728 to 764 pegs plus fruits/$m^2$. Pegs continued to penetrate into the soil and proceed to stage 3, but under 75% shade very few pegs developed into fully-expanded fruits (with or without rigid shells, stage 5 or 4, respectively). The first mature fruit, stage 5 (fruit with a rigid shell) (Table 6), was found at day 69. Low light intensity at this stage (treatment $G_7$) reduced the total number and dry weight of older pegs (stage 4), but not mature fruits (stage 5). Shade near the end of peak flowering or early pegging stage affected the development of late flowers and younger pegs. However, the plants still had enough time to recover and carried a sufficient number of fruits to

Table 15. Effects of different shading treatments during pegging stage on flowers, peg and pod development, and their dry weight.

| Measured responses | Age of plant in days | | | | | |
|---|---|---|---|---|---|---|
| | 69 | | 76 | | 83 | |
| | Treatment | | | | | |
| | C | G7 | C | G14 | C | G21 |
| Flower (No./m$^2$) 1/ | 98$^a$ | 8$^b$ | 16$^a$ | 0 | 5 | 0 |
| Peg & Pod (No./m$^2$) 1/ | | | | | | |
| 1 | 207 | 140 | 156 | 117 | 187$^a$ | 63$^b$ |
| 2 | 389 | 266 | 210 | 229 | 165 | 159 |
| 3 | 454 | 308 | 501$^a$ | 393$^b$ | 510 | 478 |
| 4 | 60$^a$ | 7$^b$ | 148$^a$ | 15$^b$ | 160$^a$ | 34$^b$ |
| 5 | 9 | 7 | 44a | 10b | 169a | 21b |
| Peg & Pod (g/m$^2$) 1/ | | | | | | |
| 1 | 1.0 | 0.6 | 1.7$^a$ | 0.7$^b$ | 2.3$^a$ | 0.4$^b$ |
| 2 | 4.9 | 3.4 | 3.4 | 2.7 | 2.7 | 1.6 |
| 3 | 15.9$^a$ | 9.2$^b$ | 18.1$^a$ | 11.5$^b$ | 17.1 | 14.0 |
| 4 | 8.9$^a$ | 2.1$^b$ | 30.7$^a$ | 2.6$^b$ | 23.0$^a$ | 6.4$^b$ |
| 5 | 5.4 | 3.0 | 19.4$^a$ | 5.8$^b$ | 85.4$^a$ | 13.9$^b$ |
| Top Wt. (g/m$^2$) 2/ | 400.3$^a$ | 338.3$^b$ | 577.1$^a$ | 344.2$^b$ | 612.1$^a$ | 406.4$^b$ |
| Root Wt. (g/m$^2$) 2/ | 12.3$^a$ | 9.6$^b$ | 12.5$^a$ | 9.4$^b$ | 10.7 | 11.2 |
| Repr. Wt. (g/m$^2$) 2/ | 36.2$^a$ | 17.9$^b$ | 72.7$^a$ | 23.3$^b$ | 130.5$^a$ | 36.4$^b$ |

1/ Each value is the average of 4 replications of 10 plants each.

2/ Each value is the average of 4 replications of 30 plant samples.

Values of the same row of the same age not followed by the same letter are significantly different at 5% level.

compensate for the loss of late flowers, thereby preventing a serious reduction in yield at the end of the season. At the end of the treatments $G_{14}$ and $G_{21}$, only 30 and 16% of mature fruits by weight were found in comparison with the unshaded check plots. This reduction in yield components agrees with many authors working on crops other than peanuts (Prine, 1976, 1977; Pepper and Prine, 1972).

The effects of shading for 7, 14, and 21 days during pod filling stage are summarized in Table 16. Shading for 7 days at the pod filling stage (treatment $P_7$, from days 83 to 90) caused no effects on peg and pod number and dry weight. A reduction in dry weight of all plant parts was found in shaded plants, although it was not significantly different. The results from 14-day shading during pod filling (treatment $P_{14}$) on the pegs and pods were similar to that of the 21-day shading during the same stage of growth. This stage was considered as the maximum stage of pod formation. The younger pegs were not reduced in number under stress, but their weight was decreased by 30%. The peg and pod load at this stage reached a maximum by day 97. Plants reached the maximum number of pegs and pods per unit land area, at the same time in both the 1975 and 1976 experiments, even though the population was different. Lack of full sunlight at this stage (from days 83 to 97) reduced number and dry weight of nearly mature and mature fruits by 45 and 50%, respectively. Shading for 21 days at pod filling (treatment $P_{21}$, from days 83 to 104) reduced weight and number of mature fruits by 50%. There were 329 fruits in categories 4 and 5 (expanded) at 83 days (prior to shading). There was no increase in category 4 and 5 fruits during 7, 14, and 21 days of 75% shade (83 to 104 days) (Table 16). This indicated an overwhelming effect of low light intensity on

Table 16. Effects of different shading treatments during the pod filling period on top, root, peg and pod development, and their dry weight.

| Measured responses | Age of plant in days | | | | | |
|---|---|---|---|---|---|---|
| | 90 | | 97 | | 104 | |
| | Treatment | | | | | |
| | C | $P_7$ | C | $P_{14}$ | C | $P_{21}$ |
| Peg & Pod (No./m$^2$) 1/ | | | | | | |
| 1 | 116 | 138 | 116$^a$ | 70$^b$ | 67 | 34 |
| 2 | 220 | 245 | 196 | 239 | 199 | 191 |
| 3 | 729 | 705 | 665 | 548 | 608 | 594 |
| 4 | 76 | 59 | 187$^a$ | 66$^b$ | 146$^a$ | 68$^b$ |
| 5 | 277 | 243 | 372$^a$ | 204$^b$ | 488$^a$ | 243$^b$ |
| Peg & Pod Wt. (g/m$^2$) 1/ | | | | | | |
| 1 | 1.3 | 1.2 | 0.8 | 0.4 | 0.8$^a$ | 0.2$^b$ |
| 2 | 5.1 | 4.1 | 3.5 | 3.4 | 4.8$^a$ | 2.7$^b$ |
| 3 | 25.3 | 21.7 | 24.7$^a$ | 15.2$^b$ | 19.8$^a$ | 15.4$^b$ |
| 4 | 14.4 | 8.7 | 36.7$^a$ | 8.5$^b$ | 29.6$^a$ | 10.0$^b$ |
| 5 | 173.1 | 143.9 | 294.8$^a$ | 151.6$^b$ | 402.2$^a$ | 191.3$^b$ |
| Top Wt. (g/m$^2$) 2/ | 658.0 | 612.9 | 743.4$^a$ | 627.4$^b$ | 657.1$^a$ | 532.8$^b$ |
| Root Wt. (g/m$^2$) 2/ | 13.4 | 13.9 | 17.2 | 13.7 | 15.8 | 15.9 |
| Repr. Wt. (g/m$^2$) 2/ | 219.3 | 180.3 | 360.5$^a$ | 179.1$^b$ | 457.1$^a$ | 219.8$^b$ |

1/ Each value is the average of 4 replications of 10 plants each.

2/ Each value is the average of 4 replications of 30 plants each.

Values in the same row of the same age not followed by the same letter are significantly different at 5% level.

pod expansion processes. During 83 to 104 days, the control plants increased the fruits in these categories, 4 and 5, from 329 to 634 per $m^2$. Partitioning to reproductive growth was maximum at this stage, and vegetative growth was nearly terminated; as a result the shading effects were concentrated on the pegs and pods rather than vegetative growth. The most important effects of shading during this time were on the formation of rigid shells (treatments P).

The effects of shading during maturity stage (treatments $M_7$, $M_{14}$, and $M_{21}$, from days 104 to 125) were quite similar for the three different shading durations (Table 17). The 75% reduction of light intensity during maturity interrupted the fruit formation from stage 1 to stage 5 (mature fruit). Field observations at this time indicated five newly-formed pegs were also found in this stage of growth, and shaded plants still had some flowers during the pod filling and maturing stages of plant growth. Shade also significantly reduced the dry weight of immature and mature fruits.

In general, 75% shading reduced vegetative growth during the early growing season, with smaller reduction on reproductive growth. During the pod filling and maturing stages, the main effects of shade was to reduce reproductive growth rather than vegetative growth. The effect of 75% shade on reproductive development was to reduce flowering (but not completely), to reduce peg formation (but only after seven days of shading), and primarily, to inhibit peg expansion into fully-expanded, full-sized fruits. The latter effect was nearly immediate and served to reduce fruit numbers carried. Once a fully-expanded fruit was formed, the seeds growing inside had priority over other growth processes.

Table 17. Effects of different shading treatments during the maturing stage on top, root, peg and pod development, and their dry weight.

| Measured responses | Age of plant in days | | | | | |
|---|---|---|---|---|---|---|
| | 111 | | 118 | | 125 | |
| | Treatment | | | | | |
| | C | $M_7$ | C | $M_{14}$ | C | $M_{21}$ |
| Peg & Pod (No./$m^2$) 1/ | | | | | | |
| 1 | 54 | 23 | 30 | 10 | 9 | 5 |
| 2 | 234$^a$ | 119$^b$ | 198 | 177 | 124 | 134 |
| 3 | 660 | 439 | 555 | 513 | 567 | 496 |
| 4 | 136$^a$ | 77$^b$ | 134 | 101 | 93 | 93 |
| 5 | 575$^a$ | 382$^b$ | 572$^a$ | 406$^b$ | 674$^a$ | 431$^b$ |
| Peg & Pod Wt. (g/$m^2$) 1/ | | | | | | |
| 1 | 0.7 | 0.2 | 0.2$^a$ | 0.1$^b$ | 0.1 | 0.0 |
| 2 | 5.2$^a$ | 2.4$^b$ | 4.4 | 3.4 | 2.8 | 2.1 |
| 3 | 18.7 | 13.7 | 18.8 | 13.3 | 20.6 | 13.1 |
| 4 | 20.1$^a$ | 10.1$^b$ | 25.3$^a$ | 12.4$^b$ | 17.1$^a$ | 11.0$^b$ |
| 5 | 527.5$^a$ | 348.2$^b$ | 546.9$^a$ | 387.2$^b$ | 703.4$^a$ | 439.4$^b$ |
| Top Wt. (g/$m^2$) 2/ | 678.7$^a$ | 593.1$^b$ | 736.0$^a$ | 596.6$^b$ | 679.8 | 614.2 |
| Root Wt. (g/$m^2$) 2/ | 17.3 | 15.6 | 13.4 | 13.8 | 12.1 | 14.1 |
| Repr. Wt. (g/$m^2$) 2/ | 572.2$^a$ | 374.6$^b$ | 595.6$^a$ | 416.3$^b$ | 743.9$^a$ | 465.7$^b$ |

1/ Each value is the average of 4 replications of 10 plants each.

2/ Each value is the average of 4 replications of 30 plants each.

Values in the same row of the same age not followed by the same letter are significantly different at 5% level.

Percentage of pegs forming fruits. Total number of pegs and fruits and the percentage of pegs forming fruit are summarized in Table 18. Only 1.25% of the pegs produced fruit by 76 days for treatment $G_{14}$, compared with 4.15% for the normal plants. The reduced proportion of fruiting sites forming pods is caused by the lack of photosynthetic metabolites under low light intensity. Shading for 21 days at the same stage ($G_{21}$) significantly decreased the total number of pegs and fruits and the percentage of pegs forming fruits, but it slightly increased the average mature fruit weight. The higher average mature fruit weight under shade suggests that seed growth has priority over peg formation and fruit development. This average also resulted because shade stress caused a lower number of fruit to share the reduced amount of photosynthate. Slower fruit formation and peg degeneration may be considered as the main factors contributing to the lower percentage of pegs forming fruits.

At 97 days, minor effect of shade on the total number of pegs and fruitsand on the percentage of mature fruitswas observed. A significant decrease in total number of pegs and fruitsmay be caused by the degeneration of the very young pegs under shade. A highly significant difference in percentage of mature pods occurred during 21-day shading during pod filling stage (treatment $P_{21}$), but not in average fruit weight. Low light intensity at this stage inhibited additional formation of fully-expanded fruits; therefore, fewer full-sized fruits shared the energy available for pod filling. This can be explained if low light intensity allowed a plant to continue pod filling while inhibiting pod formation. During maturity, the effect of low light intensity primarily affected the number and percentage of mature fruits.

Table 18. Effects of shading on total number of pegs and pods, average mature pod weight, and percentage of pegsforming pods at different stages of growth.

| Age | Trt | Peg + Pod | Expanded fruit (Stages 4 + 5) | Mature Fruit | |
|---|---|---|---|---|---|
| | | | | % | mg/pod |
| | | no./$m^2$ | No./$m^2$ | | |
| 48 | C | 39 | 0 | | |
| | $F_7$ | 20 ** | 0 | | |
| 55 | C | 200 | 0 | | |
| | $F_{14}$ | 126*** | 0 | | |
| 62 | C | 422 | 11 | | |
| | $F_{21}$ | 264** | 2 NS | | |
| 69 | C | 1119 | 69 | 0.83 | 594 |
| | $G_7$ | 728* | 14** | 0.93 NS | 470** |
| 76 | C | 1059 | 192 | 4.15 | 432 |
| | $G_{14}$ | 764*** | 25** | 1.25*** | 577* |
| 83 | C | 1191 | 329 | 14.30 | 509 |
| | $G_{21}$ | 755*** | 55** | 2.72*** | 686* |
| 90 | C | 1418 | 353 | 19.77 | 627 |
| | $P_7$ | 1390 NS | 302 NS | 17.65 NS | 589 NS |
| 97 | C | 1536 | 559 | 24.14 | 800 |
| | $P_{14}$ | 1127* | 270** | 19.07* | 741 NS |
| 104 | C | 1508 | 634 | 32.46 | 822 |
| | $P_{21}$ | 1130** | 311** | 21.72*** | 787 NS |
| 111 | C | 1659 | 711 | 36.31 | 915 |
| | $M_7$ | 1040* | 459** | 37.06 NS | 900 NS |
| 118 | C | 1489 | 706 | 38.91 | 956 |
| | $M_{14}$ | 1207 NS | 507** | 34.02 NS | 955 NS |
| 125 | C | 1467 | 767 | 46.32 | 1041 |
| | $M_{21}$ | 1159 NS | 524** | 37.48** | 1021 NS |

Each value is the average of 4 replications of 10 plants each.
NS = No significant difference.
* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

Fruit and seed sizes. Size and weight of fruits and seeds are summarized in Tables 19, 20, 21, 22, 23, 24, 25, and 26 for eight sampling dates. Grading the fruits and seeds of these samples showed that fruit and seed were well distributed in all sizes from very small to medium (size I to size III).

Within the same size of fruits and seeds, calculated average weight per fruit or seed was slightly greater for shaded plants than the control ones immediately after shade, treatments $G_{14}$ and $G_{21}$. At day 76, about 30% of the total weight of fruits was found in the smallest size on the shaded plots compared with 50% for control plots. This may be caused by the additional formation of the immature fruits on the control plants which did not occur on shaded plants. The smallest seed size contributed more than 50% to the total number of seeds recovered from the shaded plants, and more than 80% of the total number of seeds in unshaded plants (Table 19). Shade for 21 days at pegging stage similarly reduced the number of very small and small fruits by 90 and 88%, respectively (sizes I and II), and the number of seeds in sizes I and II (very small and small seeds) by 94 and 100%, respectively (Table 20).

Shading for seven days during pod filling (treatment $P_7$), (Table 21), had no significant effects on fruit and seed size, but the continued shading for 14 or 21 days during this stage caused the decrease in both number and dry weight of all fruit and seed sizes (Tables 22 and 23). The longer the length of shading, the greater the decline in weight and number of fruits and seeds in all sizes. A 50% reduction was found in both weight and number of very small and small sized fruits and seeds (Table 22) and nearly 70% in weight and number of fruit and seed size II (Table 23).

Table 19. Effects of shading on fruit[a] and seed size[a] and their dry weight at 76 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $G_{14}$ | C | $G_{14}$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 22a | 3b | -- | -- |
| II | 21a | 5b | -- | -- |
| III | 1 | 2 | -- | -- |
| Total | 44a | 10b | 19.4a | 5.8b |
| | | Seed | | |
| I | 71a | 10b | 6.3a | 1.6b |
| II | 8 | 4 | 2.2 | 1.2 |
| III | 6 | 4 | 1.4 | 0.9 |
| Total | 85a | 18b | 9.9a | 3.7b |

[a] Each value is the average of 4 replications of ten plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 20. Effects of shading on fruit[a] and seed size[a] and their dry weight at 83 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $G_{21}$ | C | $G_{21}$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 100a | 10b | -- | -- |
| II | 65a | 8b | -- | -- |
| III | 5 | 3 | -- | -- |
| IV | 0 | 0 | -- | -- |
| Total | 170a | 21b | 85.4a | 14.0b |
| | | Seed | | |
| I | 272a | 16b | 33.8a | 2.0b |
| II | 18a | 0b | 3.9a | 0.0b |
| III | 23 | 22 | 7.1 | 6.7 |
| IV | 0b | 1a | 0.0b | 0.5a |
| Total | 313a | 39b | 44.8a | 9.3b |

[a] Each value is the average of 4 replications of 10 plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 21. Effects of shading on fruit[a] and seed size[a] and their dry weight at 90 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $P_7$ | C | $P_7$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 202 | 160 | -- | -- |
| II | 72 | 75 | -- | -- |
| III | 3 | 8 | -- | -- |
| IV | 0 | 0 | -- | -- |
| Total | 277 | 243 | 173.1 | 143.9 |
| | | Seed | | |
| I | 269 | 272 | 45.9 | 44.1 |
| II | 102 | 78 | 22.9 | 19.8 |
| III | 132 | 92 | 43.9 | 30.4 |
| IV | 3 | 1 | 1.0 | 0.5 |
| Total | 506 | 443 | 113.7 | 94.8 |

[a] Each value is the average of 4 replications of 10 plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 22. Effects of shading on fruit[a] and seed size[a] and their dry weight at 97 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $P_{14}$ | C | $P_{14}$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 248a | 128b | -- | -- |
| II | 119a | 72b | -- | -- |
| III | 5 | 4 | -- | -- |
| IV | 0 | 0 | -- | -- |
| Total | 372a | 204b | 294.8a | 151.6b |
| | | Seed | | |
| I | 167a | 97b | 28.8a | 17.8b |
| II | 78 | 75 | 25.9 | 20.6 |
| III | 394a | 196b | 145.7a | 70.6b |
| IV | 17a | 5b | 8.8a | 2.5b |
| Total | 656a | 373b | 209.2a | 111.5b |

[a] Each value is the average of 4 replications of 10 plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 23. Effects of shading on fruit[a] and seed size[a] and their dry weight at 104 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $P_{21}$ | C | $P_{21}$ |
| | No./ $m^2$ | No./ $m^2$ | g/$m^2$ | g/$m^2$ |
| | | Fruit | | |
| I | 335a | 167b | 244.9a | 114.1b |
| II | 148a | 71b | 149.9a | 70.2b |
| III | 5 | 5 | 7.4 | 7.1 |
| IV | 0 | 0 | 0 | 0 |
| Total | 488a | 243b | 402.2a | 191.4b |
| | | Seed | | |
| I | 247a | 80b | 34.9a | 10.3b |
| II | 86a | 52b | 27.8a | 14.7b |
| III | 472a | 280b | 199.4a | 104.4b |
| IV | 37a | 17b | 21.5a | 8.9b |
| Total | 842a | 429b | 283.6a | 141.3b |

[a] Each value is the average of 4 replications of 10 plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

During the maturation stage, the energy captured by the plants was used in seed growth rather than fruit formation. As a result, remaining fruits from treatments $M_7$, $M_{14}$, and $M_{21}$, filled as rapidly and were at least as heavy as control fruits at days 111 and 118, to compensate for the lower percentage of mature fruits (Table 18). Sizes and weight of mature fruits of these treatments ($M_7$, $M_{14}$, and $M_{21}$) were also affected by low light intensity (Tables 24, 25, and 26). Shade reduced the number of mature fruits, particularly the very small fruits (size I). Significant differences were found in number and dry weight of very small and small seeds (sizes I and II) between shaded plants and control plants.

Shelling percentage. Light intensity was negatively correlated with shelling percentage, particularly at the longer shading periods which increased the shelling percentage (Table 27). During the pod filling and maturation stages, shading for seven days did not cause much effect on shelling percentage. An explanation for the higher shelling percentage of shaded fruits immediately after shading is that shade prevented fruit formation as stated before, whereas seed growth had priority over fruit expansion. Thus existing fruits continued to fill seeds, but no immature fruits were added during the shade period.

## Final Yield

First year experiment. Yield of fruit, average fruit weight, percentage of extra large seeds, and other yield components are shown in Table 12. First fully-expanded mature fruit appeared around 70 days after planting with a pod weight varying from 420 to 570 mg. Pod weight increased with the time after the shell was completely formed. During the shade period, most of the photosynthetic metabolites were

Table 24. Effects of shading on fruit[a] and seed size[a] and their dry weight at 111 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $M_7$ | C | $M_7$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 434a | 270b | 359.0a | 217.6b |
| II | 137 | 108 | 163.1 | 124.7 |
| III | 4 | 4 | 5.4 | 5.9 |
| IV | 0 | 0 | 0 | 0 |
| Total | 575a | 382b | 527.5 | 348.2b |
| | | Seed | | |
| I | 244 | 143 | 38.8 | 20.8 |
| II | 101a | 49b | 26.2a | 13.1b |
| III | 647a | 435b | 294.5a | 203.2b |
| IV | 62 | 39 | 36.9 | 23.5 |
| Total | 1054a | 666b | 396.4a | 260.6b |

[a] Each value is the average of 4 replications of ten plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 25. Effects of shading on fruit[a] and seed size[a] and their dry weight at 118 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $M_{14}$ | C | $M_{14}$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 431a | 300b | 377.5a | 258.9b |
| II | 133 | 102 | 172.4 | 121.3 |
| III | 8 | 4 | 11.0a | 6.7b |
| IV | 0 | 0 | 0 | 0 |
| Total | 572a | 406b | 560.9a | 386.9b |
| | | Seed | | |
| I | 146a | 80b | 21.6a | 10.8b |
| II | 58 | 41 | 13.6 | 11.4 |
| III | 674a | 514b | 320.9a | 234.6b |
| IV | 81 | 65 | 47.9 | 38.6 |
| Total | 959a | 700b | 404.0a | 295.4b |

[a] Each value is the average of 4 replications of 10 plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 26. Effects of shading on fruit[a] and seed size[a] and their dry weight at 125 days.

| Size | Treatment | | | |
|---|---|---|---|---|
| | C | $M_{21}$ | C | $M_{21}$ |
| | No./ $m^2$ | No./ $m^2$ | $g/m^2$ | $g/m^2$ |
| | | Fruit | | |
| I | 487a | 317b | 430.4a | 286.7b |
| II | 182 | 111 | 264.8 | 146.1 |
| III | 5 | 4 | 8.1 | 6.7 |
| IV | 0 | 0 | 0 | 0 |
| Total | 674a | 432b | 703.3a | 439.5b |
| | | Seed | | |
| I | 112 | 79 | 15.1a | 8.9b |
| II | 36a | 19b | 8.9a | 5.8b |
| III | 814a | 546b | 398.9a | 270.7b |
| IV | 203a | 105b | 128.7a | 64.0b |
| Total | 1165a | 749b | 551.7a | 349.4b |

[a] Each value is the average of 4 replications of 10 plants each.

Values of the same row of the category not followed by the same letter are significantly different at 5% level.

Table 27. Effects of shading on shelling percentage. Measured after shading interval of each treatment.

| | Age of Plant (days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 67 | 83 | 90 | 97 | 104 | 111 | 118 | 125 |
| | Duration of Treatment (days) | | | | | | | |
| | 14 | 21 | 7 | 14 | 21 | 7 | 14 | 21 |
| Control | 51.1b | 52.4b | 65.7 | 71.0b | 70.5b | 75.1 | 73.9 | 78.4b |
| Shaded | 62.9a | 66.7a | 65.9 | 73.5a | 73.9a | 75.9 | 76.3 | 79.5a |

Each value is the average of 4 replications of 10 plants each.

Values in the same column not followed by the same letter are significantly different at 5% level.

used for pod filling rather than for other reproductive processes (Hudgens et al., 1975). The number of pods and pegs and the percentage of mature fruits showed that pod formation and peg elongation were interrupted by low light intensity, resulting in a lower number of mature pods, particularly during pod expansion, 83 to 93 days after planting. Dry weight per mature pod of the last two treatments P and M (from days 83 to 93 and from 104 to 114), was significantly higher than that of the check plants immediately after shading. However, this was caused by an inhibition of pod expansion from stages 3 and 4 to stage 5 during shading. This resulted in no additional light-weight pods to the mature category during shading stress, thus the average weight of mature pods increased as well as the shelling percentage. However, shading did not cause greater average mature pod weight at harvest, because additional young fruits were added after shade removal from some treatments. Shading at the peak flowering period, treatment F, gave the plants enough time to recover from the physiological stress following the removal of shades. The number of fruits was less because of the loss of active flowers. There was no drastic reduction in yield or percentage of extra large seeds at harvest. Failure to receive full sunlight during pod filling stage seemed to affect the final yield more than pod number, with lowest fruit weight, lowest percentage of extra large seeds and higher percentage of shriveled seeds (treatment P, from days 83 to 93). During the maturity period, low light intensity for 10 days showed no significant effect on fruit yield and fruit weight, but caused an increase in percentage of shriveled seeds. This may have resulted from the competition among many developing fruits. The lowest yield resulted from the shade treatment during the pod filling period, treatment P, and second lowest resulted from shade at pegging stage, treatment G.

Second year experiment. There were many significant effects of shade on yield and yield components in this experiment. Data are listed in Tables 28, 29, 30, 31, and 32. Three lengths of shading (7, 14, and 21 days) applied during flowering stage gave similar yields which were as high as controls. $F_{14}$ had the highest total biomass, fruit yield, and seed yield. Shading during the pegging period (treatments $G_7$, $G_{14}$, and $G_{21}$) had a greater effect on total number and dry weight of fruits and pegs (Tables 18 and 28); however, number of harvestable fruits was similarly reduced to that of other shade treatments during pod filling and maturation. This agrees with evidence from Shear (1955) indicating that the majority of fruits resulted from flowering and fertilization occurring during the third and fourth weeks of flowering. Except during the flowering period, 14- or 21-day shading caused tremendous reductions on plant growth. Shade for seven days did not significantly reduce yield at any stage. Shade at flowering merely delayed fruit formation and the plant had enough time to recover from physiological stress following the removal of shade. Shade for 14 or 21 days at later stages of growth caused reduced plant growth and yield, fewer harvestable fruits, lower weight of these fruits, and lower percentage of mature fruits. Shading for 21 days at pod filling stage caused the largest reduction in fruit yield and seed yield (Table 30).

Shade during the first stage of growth (treatment $F_7$, $F_{14}$, and $F_{21}$) decreased the number of pegs and pods, and the total plant weight (Table 28). The number of fruits at harvest was less, but the fruit was larger

Table 28. Total biomass and yield components of peanut in second year shading experiment.

|  | Trt | Total plant | Yield | Seed yield | Harvestable fruit | Avg. fruit wt. | Shelling Percentage |
|---|---|---|---|---|---|---|---|
|  |  | $g/m^2$ | $g/m^2$ | $g/m^2$ | $No./m^2$ | mg/fruit | % |
| 1 | C | 1424.0abc | 671.8abc | 528.3abc | 617.8 | 1087 | 78.6ab |
| 2 | $F_7$ | 1488.7ab | 706.2ab | 553.3ab | 593.4 | 1190 | 78.3ab |
| 3 | $F_{14}$ | 1601.7a | 730.2a | 570.5a | 613.0 | 1191 | 78.2ab |
| 4 | $F_{21}$ | 1372.4bcd | 692.0ab | 534.4abc | 608.4 | 1137 | 77.2ab |
| 5 | $G_7$ | 1362.7bcde | 648.1abcd | 505.6abcd | 528.8 | 1225 | 78.0ab |
| 6 | $G_{14}$ | 1265.9cdef | 554.3defg | 428.0efg | 464.1 | 1194 | 77.6ab |
| 7 | $G_{21}$ | 1314.3bcde | 584.2cdef | 451.1def | 502.0 | 1164 | 77.4ab |
| 8 | $P_7$ | 1340.1bcde | 614.1bcde | 487.3bcde | 501.8 | 1224 | 79.3a |
| 9 | $P_{14}$ | 1240.0cdef | 583.8cdef | 465.6cdef | 531.7 | 1098 | 79.8a |
| 10 | $P_{21}$ | 1078.6f | 463.9g | 359.7g | 423.4 | 1095 | 77.5ab |
| 11 | $M_7$ | 1298.1bcde | 608.4bcde | 475.2cde | 550.6 | 1105 | 78.1ab |
| 12 | $M_{14}$ | 1172.2def | 534.9def | 399.2fg | 525.6 | 1017 | 74.6c |
| 13 | $M_{21}$ | 1143.1ef | 503.7fg | 361.1g | 526.6 | 956 | 71.7c |

Harvested at 145 days after planting.

Each value is the average of 4 replications of 30 plants each.

Values in the same column not followed by the same letters are significantly different at 5% level according to Duncan's multiple range test.

and this compensated for the reduced number of fruits. Tables 29, 30, 31, and 32 report fruit and seed sizes by number and mg dry weight per $m^2$ in three fruit sizes (I, II, and III) and four seed sizes (II, III, and IV). Size I seeds are not presented.

Between 50 and 65% of the fruits by weight were in category I. The average fruit weight of size I was about 900 to 1000 mg per fruit, regardless of the treatments. The fruit weight of size II varied from 1300 to 1450 mg per fruit and contributed 30 to 42% by weight of the yield. A small percentage of fruits was found in category III with an average weight of 1600 to 1800 mg per fruit. Shade treatments caused no significant effects on fruit sizes and average fruit weight. Average fruit weight and percentage of each size by weight (Table 29) indicated that shade at flowering stage tended to cause more larger fruits and fewer small fruits. Shade at pegging stage seemed to increase the weight of very small fruits (size I), although not significantly. Fruit weight slightly decreased with an increase in duration of shading.

The percentage of medium seeds (size III) seemed to increase with increasing length of shade during pod filling stage (treatment P) although the percentage of larger seeds (size IV) decreased proportionally (Table 32). A higher percentage of small seeds was found when shade was applied at maturity, although this difference was not significant. Most of the seeds of the treatment M were in medium size (III) which contributed more than 70% of the total yield. Average seed weight of size III varied from 500 to 550 mg per seed. The small seeds (II) contributed 2 to 3% to yield and had an average weight of 250 to 270 mg per seed. Larger seed was about 680 to 700 mg per seed, and contributed more than 25% of the seed yield (Table 31).

Table 29. Effects of shading on fruit weight and percentage of different fruit sizesat harvest.

| Trt | Fruit Diameter | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 < 10.7mm | | | | 10.7mm < 11 < 13.5mm | | | | 13.5mm < 111 < 14.3mm | | | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| | mg/fruit | | % | | mg/fruit | | % | | mg/fruit | | % | |
| C | 932 | 33 | 63.4 | 4.8 | 1467 | 66 | 36.7 | 6.9 | 1697 | 71 | 1.9 | 1.2 |
| $F_{7}$ | 990 | 64 | 57.7 | 4.4 | 1462 | 109 | 38.0 | 3.5 | 1795 | 46 | 4.4 | 1.1 |
| $F_{14}$ | 978 | 50 | 53.9 | 3.9 | 1436 | 47 | 41.0 | 2.8 | 1787 | 39 | 5.1 | 1.6 |
| $F_{21}$ | 932 | 93 | 52.1 | 7.8 | 1449 | 32 | 41.6 | 4.2 | 1684 | 108 | 6.2 | 3.6 |
| $G_{7}$ | 1034 | 18 | 55.1 | 1.9 | 1463 | 48 | 42.3 | 2.9 | 1695 | 92 | 2.6 | 1.0 |
| $G_{14}$ | 1039 | 89 | 66.0 | 6.4 | 1470 | 27 | 31.8 | 6.6 | 1605 | 21 | 1.3 | 0.5 |
| $G_{21}$ | 1018 | 98 | 64.1 | 2.0 | 1483 | 77 | 34.2 | 2.0 | 1751 | 78 | 1.6 | 0.6 |
| $P_{7}$ | 1048 | 48 | 57.3 | 6.5 | 1456 | 25 | 39.4 | 6.0 | 1728 | 38 | 3.3 | 1.1 |
| $P_{14}$ | 978 | 82 | 64.7 | 3.8 | 1410 | 38 | 33.0 | 3.3 | 1734 | 78 | 2.2 | 0.6 |
| $P_{21}$ | 948 | 55 | 66.2 | 2.3 | 1361 | 39 | 30.3 | 1.7 | 1691 | 65 | 3.5 | 1.2 |
| $M_{7}$ | 931 | 62 | 56.6 | 7.5 | 1446 | 51 | 40.7 | 7.2 | 1732 | 34 | 2.8 | 0.8 |
| $M_{14}$ | 848 | 26 | 61.8 | 3.6 | 1403 | 12 | 35.1 | 2.7 | 1713 | 51 | 3.1 | 1.5 |
| $M_{21}$ | 777 | 65 | 56.4 | 7.2 | 1375 | 63 | 39.9 | 6.1 | 1691 | 29 | 3.7 | 1.4 |

Each value of the mean is the average of 4 replications of 30 plants each.

SD = standard deviation.

Table 30. Mean and standard deviation of dry weight and number of peanut fruits of different sizes at harvest.

| Trt | Fruit Diameter | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 <10.7mm | | | | 10.7mm <11 <13.5mm | | | | 13.5mm <111 <14.3mm | | | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| | g/m$^2$ | | No./m$^2$ | | g/m$^2$ | | No./m$^2$ | | g/m$^2$ | | No./m$^2$ | |
| C | 412.6 | 65.3 | 440.9 | 52.0 | 246.1 | 52.7 | 169.3 | 44.0 | 13.0 | 9.2 | 7.6 | 4.9 |
| $F_7$ | 392.7 | 39.0 | 396.4 | 23.6 | 260.0 | 44.8 | 180.4 | 44.8 | 29.8 | 9.3 | 16.6 | 5.4 |
| $F_{14}$ | 383.2 | 65.1 | 392.5 | 67.2 | 288.5 | 16.7 | 200.8 | 8.8 | 35.1 | 8.7 | 19.7 | 6.1 |
| $F_{21}$ | 366.4 | 102.4 | 388.0 | 78.9 | 285.3 | 23.0 | 196.6 | 13.8 | 40.4 | 20.8 | 23.5 | 10.3 |
| $G_7$ | 347.6 | 50.2 | 336.4 | 48.3 | 266.5 | 38.3 | 183.1 | 33.8 | 16.0 | 7.9 | 9.3 | 4.4 |
| $G_{14}$ | 354.3 | 34.7 | 342.8 | 39.3 | 171.9 | 59.0 | 116.8 | 39.2 | 7.2 | 3.3 | 4.5 | 2.0 |
| $G_{21}$ | 367.1 | 55.8 | 364.2 | 71.4 | 195.3 | 23.5 | 132.3 | 19.9 | 9.6 | 4.6 | 5.5 | 2.5 |
| $P_7$ | 343.7 | 67.3 | 330.2 | 54.4 | 233.1 | 28.9 | 160.2 | 20.3 | 19.6 | 8.0 | 11.4 | 4.8 |
| $P_{14}$ | 377.7 | 54.1 | 386.9 | 48.5 | 193.4 | 35.7 | 137.5 | 26.5 | 12.8 | 4.1 | 7.3 | 2.1 |
| $P_{21}$ | 397.9 | 44.0 | 313.6 | 35.5 | 137.4 | 27.4 | 100.7 | 17.9 | 15.5 | 6.2 | 9.1 | 3.3 |
| $M_7$ | 342.2 | 41.4 | 366.9 | 24.6 | 249.6 | 66.3 | 174.2 | 52.5 | 16.6 | 5.3 | 9.5 | 2.9 |
| $M_{14}$ | 330.5 | 25.7 | 382.5 | 16.8 | 187.8 | 16.6 | 133.9 | 12.3 | 16.5 | 9.2 | 9.5 | 5.2 |
| $M_{21}$ | 283.1 | 36.6 | 369.0 | 74.2 | 201.6 | 44.3 | 146.4 | 28.6 | 19.9 | 9.2 | 11.2 | 5.4 |

Each value of the mean is the average of 4 replications of 30 plants each.

SD = standard deviation.

Table 31. Effects of shading on seed weight and its percentage of different seed sizes at harvest.

| Trt | Seed Size | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6mmx19mm <II <6.4mmx19mm | | | | 6.4mmx19mm <III< 8.5mmx19mm | | | | 8.5mmx19mm <IV | | | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| | mg/seed | | % | | mg/seed | | % | | mg/seed | | % | |
| C | 253 | 6.3 | 1.6 | 0.5 | 539 | 7.2 | 71.7 | 4.9 | 686 | 9.4 | 26.7 | 5.1 |
| $F_7$ | 262 | 15.2 | 1.9 | 0.5 | 546 | 7.2 | 73.9 | 2.9 | 702 | 7.1 | 24.2 | 2.6 |
| $F_{14}$ | 261 | 3.3 | 1.8 | 0.2 | 534 | 17.5 | 73.3 | 3.6 | 697 | 5.5 | 24.9 | 3.7 |
| $F_{21}$ | 259 | 14.4 | 2.0 | 0.5 | 526 | 1.5 | 70.4 | 4.1 | 706 | 30.2 | 27.5 | 3.6 |
| $G_7$ | 256 | 7.2 | 1.4 | 0.3 | 571 | 20.4 | 67.0 | 1.7 | 708 | 14.3 | 31.6 | 1.8 |
| $G_{14}$ | 253 | 11.0 | 1.6 | 0.6 | 544 | 9.5 | 71.7 | 3.8 | 686 | 16.6 | 26.7 | 4.3 |
| $G_{21}$ | 264 | 7.3 | 1.7 | 0.4 | 535 | 8.3 | 67.3 | 3.6 | 707 | 6.5 | 31.1 | 3.9 |
| $P_7$ | 261 | 16.5 | 1.4 | 0.2 | 548 | 20.6 | 72.2 | 1.8 | 698 | 27.2 | 26.4 | 1.7 |
| $P_{14}$ | 262 | 10.2 | 1.7 | 0.4 | 519 | 16.3 | 78.3 | 3.5 | 657 | 15.0 | 20.0 | 3.2 |
| $P_{21}$ | 269 | 9.4 | 2.7 | 0.1 | 487 | 12.3 | 81.8 | 1.5 | 698 | 9.1 | 15.6 | 1.5 |
| $M_7$ | 266 | 7.0 | 2.3 | 0.2 | 525 | 30.5 | 73.4 | 2.8 | 713 | 16.8 | 24.3 | 2.9 |
| $M_{14}$ | 261 | 10.2 | 4.3 | 0.4 | 522 | 18.0 | 74.3 | 4.5 | 680 | 15.8 | 21.4 | 4.2 |
| $M_{21}$ | 238 | 7.0 | 2.8 | 0.3 | 537 | 8.7 | 71.7 | 2.1 | 687 | 17.5 | 25.5 | 2.1 |

Each value of the mean is the average of 4 replications of 30 plants each.

SD = standard deviation.

Table 32. Mean and standard deviation of dry weight and number of peanut seeds of different sizes at harvest.

| Trt | Seed Diameter | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6mmx19mm < 11 < 6.4mmx19mm | | | | 6.4mmx19mm < 111 < 8.5mmx19mm | | | | 8.5mmx19mm < IV | | | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| | $g/m^2$ | | $No./m^2$ | | $g/m^2$ | | $No./m^2$ | | $g/m^2$ | | $No./m^2$ | |
| C | 8.3 | 2.5 | 32.5 | 9.3 | 379.0 | 38.0 | 703.2 | 73.5 | 141.0 | 30.8 | 206.0 | 47.6 |
| $F_7$ | 10.4 | 3.8 | 40.0 | 14.0 | 409.0 | 30.4 | 749.3 | 55.0 | 133.8 | 16.8 | 190.3 | 21.9 |
| $F_{14}$ | 11.2 | 1.9 | 42.9 | 7.2 | 418.8 | 40.3 | 785.6 | 85.3 | 141.6 | 22.6 | 203.1 | 33.3 |
| $F_{21}$ | 10.6 | 2.1 | 40.7 | 6.3 | 378.3 | 70.9 | 719.3 | 136.4 | 145.5 | 17.8 | 207.0 | 31.9 |
| $G_7$ | 7.1 | 1.6 | 27.6 | 5.8 | 338.0 | 22.6 | 592.2 | 43.8 | 160.5 | 24.9 | 227.2 | 38.7 |
| $G_{14}$ | 6.8 | 3.0 | 26.5 | 10.5 | 306.5 | 47.0 | 562.3 | 76.2 | 114.6 | 30.8 | 167.0 | 43.7 |
| $G_{21}$ | 7.6 | 2.1 | 28.5 | 7.8 | 304.1 | 43.3 | 569.3 | 88.5 | 139.4 | 17.6 | 197.4 | 26.7 |
| $P_7$ | 6.9 | 0.6 | 26.4 | 2.1 | 352.4 | 40.9 | 645.0 | 86.3 | 128.0 | 3.8 | 183.9 | 13.6 |
| $P_{14}$ | 8.0 | 1.9 | 30.3 | 6.5 | 366.0 | 65.5 | 703.9 | 113.4 | 91.6 | 8.9 | 139.5 | 14.3 |
| $P_{21}$ | 9.6 | 0.5 | 35.7 | 3.1 | 293.9 | 26.2 | 603.7 | 55.8 | 56.2 | 9.9 | 80.5 | 13.8 |
| $M_7$ | 10.7 | 0.9 | 40.2 | 2.9 | 349.2 | 40.8 | 665.6 | 66.8 | 115.3 | 16.3 | 161.8 | 22.7 |
| $M_{14}$ | 17.2 | 2.3 | 66.0 | 9.1 | 296.8 | 28.1 | 567.8 | 40.2 | 85.1 | 18.5 | 124.9 | 25.9 |
| $M_{21}$ | 10.0 | 0.9 | 42.3 | 5.2 | 258.6 | 13.0 | 481.2 | 22.0 | 92.3 | 14.6 | 134.4 | 20.9 |

Each value of the mean is the average of 4 replications of 30 plants each.

SD = standard deviation.

## Comparison of Experimental Data to Simulated Results from PENUTZ Model

The PENUTZ Simulation Model was first written by W. G. Duncan, 1974. The growth, development, and fruiting of the peanut crop is described by a computer simulation model, that mimics the physiological processes presumed to operate in the plants. This model produces a quantitative description of the behavior of peanut in variable environments. Input information includes varietal characteristics such as fruit weight, oil and protein analysis, flowering characteristics, and growth habit; daily climatic data of solar radiation, maximum and minimum temperatures, and rainfall as irrigation; and soil moisture and rooting characteristics. With this input information, the simulator predicts yield and quality of fruit at any harvest date as well as description of the growing plant.

Thus, Florunner peanut characteristics were used with 1975 Gainesville weather, planting date, harvesting date, plant population, and shading periods to predict the effects of these shade treatments on yield and quality of this variety. Two years of field experiments were conducted to validate hypotheses established with the use of this simulation model. Weekly experimental data was compared with weekly predicted data from this model. The predicted flowering period spanned 40 days (from 30 to 70 days after planting), and the first flower was observed at day 30, and about one week later the first peg was formed. Daily flowers were reduced under shade conditions as predicted by this model. Total biomass of the plants increased linearly with a slower rate at the expansion phase and during maturity. Table 33 compares weekly observations of the experimental data to model predictions.

Table 33. Total biomass and yield components of peanut predicted by PENUTZ model and experimental data as affected by shade.

| Trt | Age | Flower | Undeveloped pegs | Peanuts | Leaf + stem | Total peanuts | Harvestable peanuts | Total biomass |
|---|---|---|---|---|---|---|---|---|
| | | No./m$^2$ | No./m$^2$ | No./m$^2$ | g/m$^2$ | g/m$^2$ | g/m$^2$ | g/m$^2$ |
| C | 48 | 21 | 31 | 0 | 225 | 1 | 0 | 234 |
| | | 33 | 36 | 0 | 130 | 1 | 0 | 144 |
| $F_7$ | | 7 | 33 | 0 | 136 | 1 | 0 | 145 |
| | | 21 | 20 | 0 | 104 | 1 | 0 | 107 |
| C | 55 | 27 | 107 | 0 | 390 | 5 | 0 | 407 |
| | | 36 | 200 | 0 | 224 | 3 | 0 | 234 |
| $F_{14}$ | | 13 | 99 | 0 | 165 | 6 | 0 | 180 |
| | | 20 | 126 | 0 | 136 | 1 | 0 | 141 |
| C | 62 | 27 | 235 | 0 | 507 | 22 | 0 | 545 |
| | | 81 | 422 | 0 | 293 | 10 | 0 | 312 |
| $F_{21}$ | | 3 | 134 | 0 | 173 | 19 | 0 | 203 |
| | | 17 | 264 | 0 | 176 | 4 | 0 | 184 |
| C | 69 | 5 | 407 | 3 | 532 | 66 | 3 | 632 |
| | | 98 | 1110 | 9 | 400 | 36 | 5 | 449 |
| $G_7$ | | 0 | 410 | 0 | 497 | 30 | 0 | 548 |
| | | 8 | 721 | 7 | 338 | 18 | 3 | 366 |
| C | 76 | 0 | 484 | 24 | 537 | 133 | 28 | 707 |
| | | 16 | 1115 | 44 | 577 | 73 | 19 | 662 |
| $G_{14}$ | | 0 | 508 | 1 | 497 | 35 | 1 | 553 |
| | | 0 | 754 | 10 | 334 | 23 | 6 | 367 |

Table 33 - Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C | 83 | 0 | 454 | 59 | 537 | 220 | 75 | 797 |
| | | 5 | 1022 | 169 | 612 | 130 | 85 | 753 |
| $G_{21}$ | | 0 | 335 | 3 | 497 | 45 | 3 | 562 |
| | | 0 | 734 | 21 | 406 | 36 | 14 | 454 |
| C | 90 | 0 | 273 | 144 | 537 | 319 | 189 | 900 |
| | | 0 | 1141 | 277 | 658 | 219 | 173 | 1011 |
| $P_7$ | | 0 | 339 | 77 | 537 | 230 | 100 | 809 |
| | | 0 | 1147 | 243 | 612 | 180 | 143 | 807 |
| C | 97 | 0 | 175 | 235 | 537 | 402 | 329 | 989 |
| | | 0 | 1164 | 372 | 743 | 360 | 295 | 991 |
| $P_{14}$ | | 0 | 320 | 90 | 537 | 237 | 119 | 817 |
| | | 0 | 923 | 204 | 627 | 179 | 152 | 820 |
| C | 104 | 0 | 123 | 287 | 537 | 478 | 436 | 1066 |
| | | 0 | 1020 | 488 | 657 | 457 | 402 | 1130 |
| $P_{21}$ | | 0 | 303 | 107 | 537 | 242 | 136 | 822 |
| | | 0 | 887 | 243 | 533 | 220 | 191 | 768 |
| C | 111 | 0 | 98 | 317 | 562 | 559 | 501 | 1178 |
| | | 0 | 1084 | 575 | 678 | 572 | 527 | 1268 |
| $M_7$ | | 0 | 501 | 306 | 537 | 482 | 376 | 1052 |
| | | 0 | 658 | 382 | 593 | 375 | 348 | 983 |
| C | 118 | 0 | 103 | 312 | 643 | 582 | 504 | 1282 |
| | | 0 | 917 | 572 | 736 | 596 | 547 | 1345 |
| $M_{14}$ | | 0 | 122 | 287 | 537 | 490 | 447 | 1082 |
| | | 0 | 801 | 406 | 597 | 416 | 387 | 1027 |

Table 33 - Continued.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C | 125 | 0 | 127 | 312 | 723 | 583 | 504 | 1362 |
| | | 0 | 793 | 674 | 680 | 744 | 703 | 1436 |
| $M_{21}$ | | 0 | 122 | 287 | 539 | 490 | 447 | 1083 |
| | | 0 | 728 | 431 | 614 | 466 | 439 | 1094 |

Upper values were obtained from the computerized PENUTZ model, the lower values were from the experimental data.

Both control and shaded field grown plants had more flowers than the values predicted by the simulation model. Experimental plants had more undeveloped pegs, regardless of shading treatments. The predicted date at which the plants produced a full-sized fruit occurred on the same day as the field experiment (69 days after planting).

Predicted top growth initially developed at a more rapid rate than field grown plants. However, near the end of the growing season, top growth and total biomass of predicted and field experimental data were similar. Total biomass and yield components of peanuts predicted by simulation of all treatments are listed in Table 34.

The development of the peanuts in field experiment was slower than the predicted plant characteristics and nearly twice as many pods were formed. However, this occurred because the simulation model apparently used a fruit size and individual fruit growth rate larger than occurred in this experiment. Average fruit weight was 20% lower in the field experiment than in the predicted fruit weight (1150 mg per fruit compared with 1450 mg per fruit of the predicted value). Note, however, that weight of total and harvestable peanuts was comparable for computer predicted and experimental results except that peanut development started too fast in the simulation.

The prediction of shading effects on vegetative and reproductive growth rates and partitioning factor is reported in Table 35. During the flowering stage (from days 41 to 62) predicted vegetative growth rate was 8.5 mg/m$^2$/day higher and reproductive growth rate was 0.5 mg/m$^2$/day higher than the growth rates of field plants. During the pegging stage, shaded plants contributed only 1.0 mg/m$^2$/day to the reproductive growth, about 0.2 mg/m$^2$/day lower than the reproductive

Table 34. Total biomass and yield components of peanut predicted by PENUTZ model under shade.

| Trt | Total plant | Yield | Total peg + pod | Harvestable fruit | Reproductive weight | Avg. fruit wt. |
|---|---|---|---|---|---|---|
| | $g/m^2$ | $g/m^2$ | No./$m^2$ | No./$m^2$ | $g/m^2$ | mg/fruit |
| C | 1474 | 504 | 641 | 312 | 625 | 1620 |
| $F_7$ | 1440 | 551 | 442 | 337 | 631 | 1630 |
| $F_{14}$ | 1343 | 651 | 491 | 397 | 662 | 1640 |
| $F_{21}$ | 1253 | 641 | 388 | 361 | 648 | 1770 |
| $G_7$ | 1375 | 633 | 450 | 411 | 652 | 1540 |
| $G_{14}$ | 1317 | 532 | 387 | 366 | 549 | 1450 |
| $G_{21}$ | 1312 | 252 | 212 | 212 | 252 | 1190 |
| $P_7$ | 1366 | 387 | 639 | 287 | 525 | 1350 |
| $P_{14}$ | 1294 | 233 | 640 | 193 | 454 | 1210 |
| $P_{21}$ | 1210 | 136 | 629 | 107 | 377 | 1270 |
| $M_7$ | 1350 | 409 | 708 | 339 | 636 | 1210 |
| $M_{14}$ | 1304 | 447 | 522 | 287 | 497 | 1550 |
| $M_{21}$ | 1236 | 447 | 470 | 287 | 491 | 1550 |

Table 35. Effects of shade on vegetative and reproductive growth rates and partitioning factor at four stages of peanut growth predicted by PENUTZ model.

| Stage | Trt | Vegetative | | Reproductive | | Corrected growth rate[a] | Corrected Biomass[b] | | Partitioning to Reproductive | Change in Partitioning |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Growth rate | Reduction | Growth rate | Reduction | | Growth rate | Reduction | | |
| | | g/$m^2$/day | % | g/$m^2$/day | % | g/$m^2$/day | g/$m^2$/day | % | % | % |
| F | C | 19.23 | | 1.02 | | 1.68 | 20.91 | | 8.0 | |
| | S | 2.94 | 84.7 | 0.86 | 15.7 | 1.42 | 3.80 | 81.8 | 37.4 | +367.5 |
| G | C | 1.35 | | 9.44 | | 15.57 | 16.92 | | 92.0 | |
| | S | -0.42 | 131.1 | 1.05 | 88.9 | 1.73 | 1.31 | 92.2 | 132.1 | +253.2 |
| P | C | 0.01 | | 12.23 | | 20.18 | 20.19 | | 100.0 | |
| | | 0.00 | 0.0 | 1.02 | 91.7 | 1.68 | 1.68 | 91.7 | 100.0 | 0.0 |
| M | C | 9.21 | | 4.81 | | 7.94 | 17.06 | | 46.5 | |
| | S | 0.07 | 99.2 | 0.63 | 86.9 | 1.04 | 1.11 | 93.5 | 93.7 | +101.5 |

[a] Corrected for fruit composition.

[b] Corrected biomass growth rate is the sum of vegetative growth rate and reproductive growth rate corrected for fruit composition.

F, G, P, and M are presented for flowering, pegging, pod filling, and maturity stages, respectively; C = control; S = shaded plants.

growth of the field plants. The predicted reproductive growth rate of plants shaded during the pegging and pod filling stages was 1 mg/m$^2$/day. This growth rate was 2.8 mg/m$^2$/day lower than the field experiment when shade was applied during the pod filling stage, and 6.0 mg/m$^2$/day lower when shade was applied at the maturity stage. The partitioning factor predicted by the PENUTZ model was high (100%) in both control and shaded plants during pod filling stage. In general, partitioning factor of the shaded plants increased at least 100% higher than the unshaded check plants, and was higher than that of the field plants under the same stage of growth, except for the shading period during the pod filling stage (Table 13).

The order of yield predicted in response to shading was almost the same as the field experiment. The PENUTZ model correctly predicted high yield for 14 and 21 days shading during the flowering period. Shading at the pod filling stage (treatments $P_{14}$ and $P_{21}$) and treatments $G_{21}$ gave the lowest yield. Yield of harvestable fruits in the field experiment was higher than the predicted yield, particularly yield of treatments during the pod filling stage ($P_7$, $P_{14}$, and $P_{21}$) and the maturity stage (treatments $M_7$, $M_{14}$, and $M_{21}$) as well as $G_{21}$. It may be suggested that the photosynthetic portion of the model is too sensitive to one to three week changes in light intensity. However, the smaller range in yield differences for experimental data suggests the model is overly responsive to shading effects.

## Fruit Growth Rate

The rate of fruit and seed growth as affected by 75% reduction in light intensity from days 83 to 104 is tabulated in Tables 36 and 37.

Table 36. Effects of shading from days 83 to 104 on fruit growth rate and seed growth rate.

| Code | Day of fruit formation[a] | Fruit growth rate |  | Seed growth rate |  |
|---|---|---|---|---|---|
|  |  | control | shading | control | shading |
|  |  | mg/day | mg/day | mg/day | mg/day |
| Y | 45 | 17.5 | 14.2[b] | 17.5 | 13.2[b] |
| B | 52 | 24.3 | 10.5[b] | 24.0 | 12.1[b] |
| M | 59 | 26.4 | 10.7 | 25.5 | 11.5 |
| R | 66 | 22.1 | 6.3[b] | 21.6 | 7.3[b] |
| W | 73 | 25.5 | 0.6[b] | 24.8 | 0.6[b] |
| O | 80 | 17.7 | 13.6 | 17.5 | 13.2 |

[a] Days after planting, the day will count as age 0 of the fruits formed from these pegs at this day.

[b] Low correlation coefficient.

Table 37. Linear models presenting the weight of fruits and seeds to age.

| Day of fruit formation | Control | $r^2$ | Shade | $r^2$ |
|---|---|---|---|---|
| 45 | $Y_1 = 430.192 + 17.524X$ | .506 | $Y_1 = 496.403 + 14.165X$ | .11 |
| | $Y_2 = 136.400 + 17.459X$ | .623 | $Y_2 = 259.273 + 13.182X$ | .13 |
| 52 | $Y_1 = -67.887 + 24.270X$ | .750 | $Y_1 = 491.475 + 10.492X$ | .12 |
| | $Y_2 = -289.703 + 23.986X$ | .807 | $Y_2 = 203.420 + 12.140X$ | .23 |
| 59 | $Y_1 = -170.186 + 26.388X$ | .819 | $Y_1 = 381.759 + 10.717X$ | .09 |
| | $Y_2 = -352.474 + 25.498X$ | .854 | $Y_2 = 144.626 + 11.518X$ | .13 |
| 66 | $Y_1 = 27.525 + 22.056X$ | .65 | $Y_1 = 511.754 + 6.247X$ | .03 |
| | $Y_2 = -170.192 + 21.631X$ | .70 | $Y_2 = 267.386 + 7.336X$ | .06 |
| 73 | $Y_1 = -145.259 + 25.476X$ | .50 | $Y_1 = 478.994 + 0.615X$ | .001 |
| | $Y_2 = -321.642 + 24.843X$ | .52 | $Y_2 = 318.398 + 0.558X$ | .001 |
| 80 | $Y_1 = 83.949 + 17.659X$ | .49 | $Y_1 = 2.347 + 13.569X$ | .32 |
| | $Y_2 = -98.240 + 17.474X$ | .53 | $Y_2 = -165.459 + 13.224X$ | .35 |

$Y_1$ and $Y_2$ are fruit weight and seed weight, respectively; X is the age of fruit or seed.

The rate of fruit development was essentially linear up until shell coloration was first observed. Beyond that point, fruit continued a slower rate of dry weight increase. Shear (1955) observed that the time of peg formation influenced the fruit filling rate. Fruits from pegs formed at 45 days after planting seemed to have a lower rate of fruit filling (17 mg/fruit/day) than fruits developed from pegs formed at 52, 59, 66, and 73 days (22 to 26 mg/fruit/day). Only a few fruits of this age existed and gave poor confidence for drawing a conclusion about the pod filling rate of the fruit produced at 45 days after planting. The majority of fruits were produced from flowering and fertilization which occurred during the third and fourth weeks of flowering. These fruits also had a higher rate of pod filling (22 to 26 mg/fruit/day).

Many single-seeded fruits were found at the time of first fruit set. It may be the characteristics of this variety or because of the competition in space close to the root system. The true reason is unknown.

Fruits formed from pegs of the third and fourth weeks after the first peg formation had similar fruit filling rate and this rate is higher than the fruit filling rate of late developed fruit (80 days after planting, 17 mg/fruit/day). The growth rate of the fruits formed at days 52, 59, 66, and 73, was lower than 35 mg/fruit/day, which Boote (1977) observed on Florunner grown in the same field. In that experiment only the first five fruits formed per plant were used. Other major differences included later planting (May 5) and lower population (15 cm spacing in 90 cm rows).

Linear regression models were also used to fit the data obtained from the fruit of shaded plots, but the data showed poorer fits except for fruit from the pegs formed at days 59 and 80. Effects of shade were most pronounced on fruits formed from pegs penetrating the soil 10 to 17 days before the shade treatment. The rate of pod filling of these fruits was much lower (0.6 and 6.3 mg/fruit/day, respectively). Schenk (1961) indicated that the pod expansion phase of a Virginia fruit required 21 days from peg penetration. Thus shading stress appears to act quickly to inhibit pod expansion of all fruits less than 21 days of age. Pegs three days old at the beginning of shading may have remained dormant until after the end of shading.

Analysis of variance showed the effects of low light intensity on fruits relative to fruit age and the date at which the pegs were formed. The three-day old pegs at date of starting shade were less effected by shading than the older fruits forming 10 and 17 days before shade treatment.

In general, fruit and seed growth rates were decreased by shade at stages of fruit expansion and seed development.

## Fruit and Seed Metabolism

Fruits from 13 to 72 days old from control and treated plants were analyzed for chemical components, i.e., oil content, sucrose, reducing sugar, starch, and total carbohydrates of shells and seeds (total $CH_2O$ content of fruit = $CH_2O$ content of seeds + $CH_2O$ content of shell).

Oil content. Percentage of oil in seeds is reported in Table 38. Figs. 10, 11, 12, 13, and 14 present the oil content in mg per fruit of shaded and control seeds related to fruit weight.

Table 38. Sucrose, reducing sugar, starch, and total carbohydrate of peanut seed and shell, and oil content.

| | | | | Shell | | | | Seed | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trt$^{a}$ | Day of fruit formation | Fruit age | Predicted fruit wt.$^{b}$ | Sucrose | Reducing sugar | Starch | Total $CH_2O$ | Sucrose | Reducing sugar | Starch | Total $CH_2O$ | Oil |
| | | | mg | % | % | % | % | % | % | % | % | % |
| 1 | 52 | 41$^{c}$ | 1120 | 0.94 | 0.18 | 0.26 | 1.39 | 1.93 | 0.18 | 6.43 | 8.54 | 46.42 |
| 2 | 52 | | 921 | 0.76 | 0.22 | 0.24 | 1.22 | 2.24 | 0.20 | 5.46 | 7.91 | 44.15 |
| 1 | 52 | 52$^{c}$ | 1257 | 0.43 | 0.23 | 0.18 | 0.83 | 2.99 | 0.09 | 3.68 | 6.76 | 44.26 |
| 2 | 52 | | 1037 | 0.48 | 0.10 | 0.37 | 0.94 | 5.21 | 0.20 | 6.16 | 11.57 | 39.07 |
| 1 | 52 | 63 | 1394 | 0.23 | 0.31 | 0.22 | 0.76 | 3.49 | 0.14 | 3.45 | 7.08 | 42.03 |
| 2 | 52 | | 1152 | 0.18 | 0.24 | 0.31 | 0.74 | 2.53 | 0.14 | 3.20 | 5.88 | 42.69 |
| 1 | 59 | 34$^{c}$ | 819 | 1.28 | 0.37 | 0.23 | 1.88 | 1.98 | 0.23 | 7.04 | 9.25 | 40.00 |
| 2 | 59 | | 746 | 1.56 | 0.52 | 0.25 | 2.33 | 2.26 | 0.37 | 6.70 | 9.33 | 40.04 |
| 1 | 59 | 45$^{c}$ | 1063 | 0.65 | 0.15 | 0.21 | 1.00 | 3.22 | 0.13 | 2.78 | 6.12 | 42.54 |
| 2 | 59 | | 864 | 0.25 | 0.25 | 0.28 | 0.78 | 5.00 | 0.18 | 4.72 | 9.90 | 38.53 |
| 1 | 59 | 56 | 1307 | 0.32 | 0.14 | 0.13 | 0.59 | 2.71 | 0.12 | 2.60 | 5.44 | 39.17 |
| 2 | 59 | | 982 | 0.25 | 0.18 | 0.27 | 0.69 | 2.55 | 0.13 | 3.70 | 6.38 | 42.51 |
| 1 | 59 | 66 | 1529 | 0.21 | 0.20 | 0.10 | 0.51 | 3.00 | 0.09 | 2.95 | 6.04 | 41.64 |
| 2 | 59 | | 1089 | 0.23 | 0.17 | 0.14 | 0.53 | 2.68 | 0.08 | 3.56 | 6.31 | 42.09 |
| 1 | 66 | 27$^{c}$ | 812 | 1.67 | 0.44 | 0.34 | 2.44 | 1.99 | 0.19 | 7.44 | 9.64 | 40.17 |
| 2 | 66 | | 680 | 1.95 | 1.01 | 0.26 | 3.22 | 2.04 | 0.30 | 8.50 | 10.85 | 34.92 |
| 1 | 66 | 38$^{c}$ | 970 | 0.34 | 0.11 | 0.23 | 0.67 | 3.69 | 0.12 | 3.52 | 7.33 | 44.59 |
| 2 | 66 | | 749 | 1.28 | 0.76 | 0.26 | 2.29 | 3.65 | 0.13 | 4.49 | 8.27 | 42.26 |
| 1 | 66 | 59 | 1272 | 0.32 | 0.15 | 0.15 | 0.63 | 3.06 | 0.11 | 2.49 | 5.67 | 44.26 |
| 2 | 66 | | 880 | 0.21 | 0.10 | 0.14 | 0.45 | 2.48 | 0.14 | 3.46 | 6.08 | 42.86 |

Table 38 - Continued.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 73 | 20[c] | 339 | 11.28 | 14.08 | 1.30 | 26.66 | 2.07 | 0.46 | 5.25 | 7.77 | 25.58 |
| 2 | 73 | | 491 | 1.71 | 0.36 | 0.97 | 3.05 | 1.32 | 0.63 | 9.40 | 11.35 | 31.96 |
| 1 | 73 | 31[c] | 631 | 0.90 | 0.29 | 0.36 | 1.55 | 3.88 | 0.11 | 3.23 | 7.22 | 44.12 |
| 2 | 73 | | 498 | 0.40 | 0.06 | 0.30 | 0.75 | 5.25 | 0.17 | 6.62 | 12.04 | 40.25 |
| 1 | 73 | 42 | 923 | 0.31 | 0.18 | 0.34 | 0.84 | 4.01 | 0.19 | 3.58 | 7.79 | 45.20 |
| 2 | 73 | | 504 | 2.31 | 6.74 | 1.28 | 10.33 | 3.70 | 0.54 | 4.08 | 8.33 | 23.06 |
| 1 | 73 | 52 | 1179 | 0.32 | 0.10 | 0.16 | 0.58 | 2.90 | 0.12 | 2.61 | 5.63 | 45.71 |
| 2 | 73 | | 510 | 2.01 | 1.05 | 0.59 | 3.65 | 4.73 | 0.26 | 6.79 | 11.79 | 40.62 |
| 1 | 73 | 72 | 1683 | 0.25 | 0.21 | 0.08 | 0.54 | 2.59 | 0.09 | 2.21 | 4.89 | 44.83 |
| 2 | 73 | | 533 | 0.39 | 0.22 | 0.15 | 0.76 | 2.68 | 0.13 | 2.98 | 5.80 | 47.89 |
| 1 | 80 | 13[c] | 307 | 27.94 | 12.35 | 1.90 | 42.20 | 1.99 | 0.37 | 2.46 | 4.83 | 27.01 |
| 2 | 80 | | 178 | 1.20 | 3.17 | 0.33 | 4.70 | 1.60 | 0.37 | 1.01 | 2.98 | 35.17 |
| 1 | 80 | 24[c] | 503 | 6.02 | 8.38 | 0.91 | 15.32 | 3.72 | 0.26 | 3.92 | 7.91 | 32.02 |
| 2 | 80 | | 328 | | | | | | | | | |
| 1 | 80 | 35 | 699 | 1.60 | 1.35 | 0.75 | 3.70 | 3.92 | 0.25 | 5.47 | 9.64 | 42.29 |
| 2 | 80 | | 477 | 9.49 | 7.59 | 2.37 | 19.44 | 3.00 | 0.31 | 4.24 | 7.56 | 22.75 |
| 1 | 80 | 45 | 878 | 0.57 | 0.10 | 0.20 | 0.88 | 3.07 | 0.12 | 2.90 | 6.08 | 48.48 |
| 2 | 80 | | 612 | 0.88 | 3.02 | 0.80 | 4.70 | 3.30 | 0.32 | 9.32 | 12.94 | 36.51 |
| 1 | 80 | 65 | 1235 | 0.21 | 0.20 | 0.08 | 0.49 | 2.96 | 0.10 | 3.00 | 6.06 | 41.86 |
| 2 | 80 | | 884 | 0.30 | 0.20 | 0.17 | 0.68 | 2.87 | 0.11 | 3.38 | 6.36 | 50.27 |

[a] 1 presents the control treatment; 2 presents the shaded treatment from days 83 to 104.

[b] Calculated by the regression models (See Table 37).

[c] Harvested during or immediately after shade treatment (i.e., at plant age 93 or 104 days).

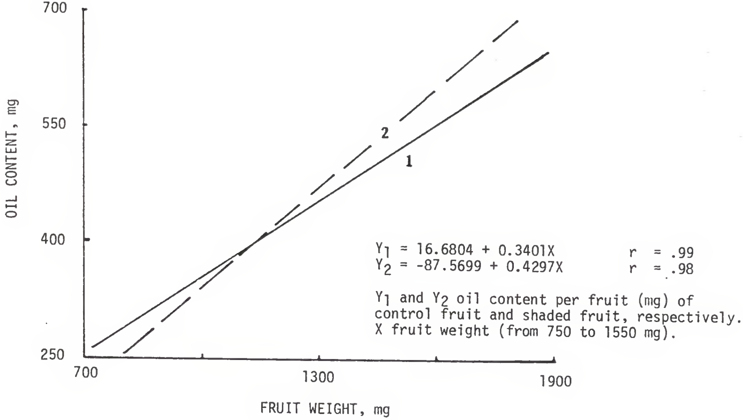


Fig. 10. Oil content of control and shaded seeds versus fruit weight of fruits formed at day 52.

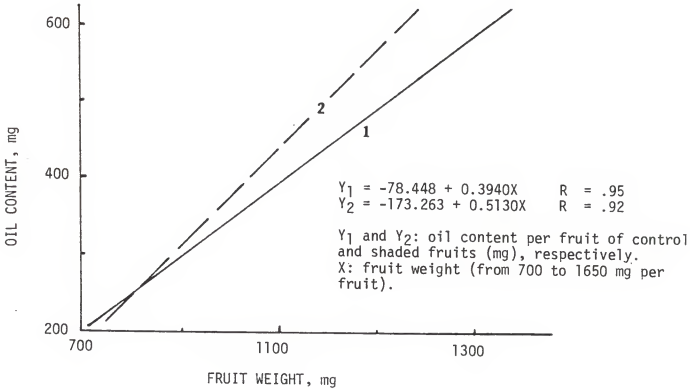


Fig. 11. Oil content of control and shaded seeds versus fruit weight of fruits formed at day 59.

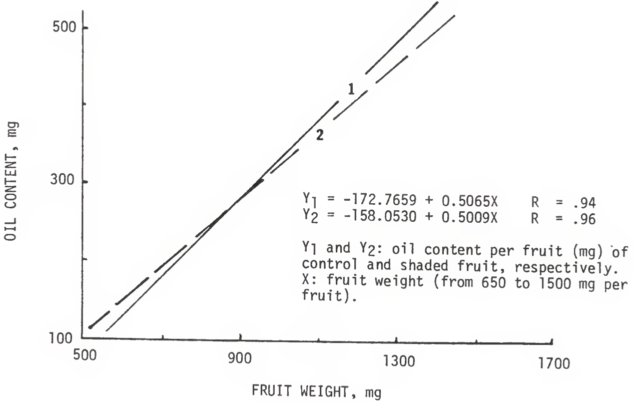


Fig. 12. Oil content of shaded and control seeds versus fruit weight of fruits formed at day 66.

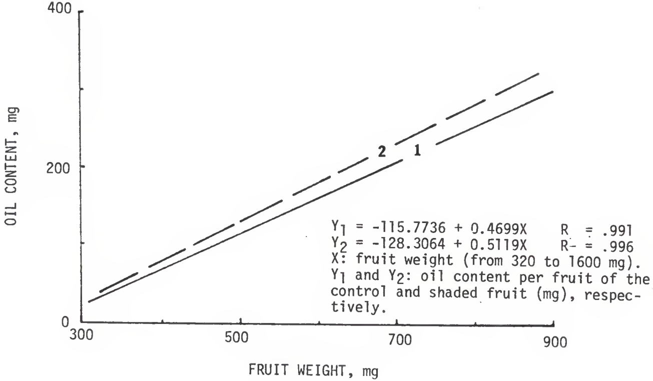


Fig. 13. Oil content of shaded and control seeds versus fruit weight of fruits formed at day 73.

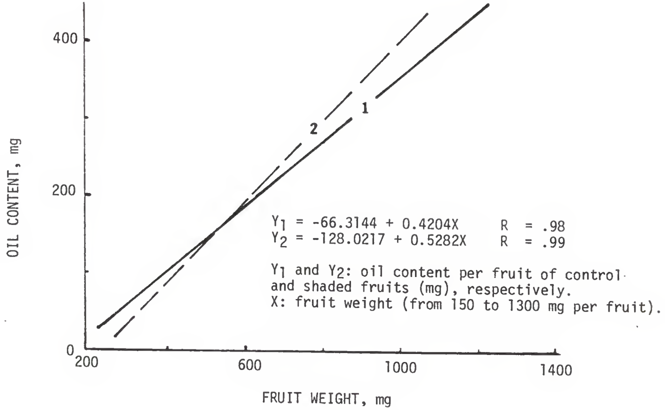


Fig. 14. Oil content of shaded and control seeds versus fruit weight of fruitsformed at day 80.

Oil content of shaded seeds was slightly higher than the control seeds for almost all fruit ages, this was particularly true for the heavier fruit weights. Oil content of seeds was positively correlated with the fruit weight, and negatively correlated with the light intensity. Percentage of oil seemed linearly related to fruit weight of the younger fruits. Percentage of oil of all fruit ages was increased during shading. The data obtained from oil extraction showed that the oil percentage sharply increased during early seed growth and increased very slowly in maturing seeds. This is similar to the observations on soybeans (McNair, 1945). Linear regression models were used to express the relationship between oil percentage of seed versus fruit weight for fruits initiated at different dates (Table 39). Analysis of variance showed significant differences in both oil content and oil percentage with age and treatment and with the interaction between age and treatment (Table 40). The increase of oil content and oil percentage of shaded plots may be related to the fact that, for a given age, the shaded fruits were lower in seed weight, and also fruit weight and the lipid metabolism of seeds had priority over the other processes.

Carbohydrate analysis. Percentage of reducing sugar, sucrose, starch of seeds, shells, and whole fruit are tabulated in Table 38. Analyses of variance on sucrose, reducing sugar, and starch of the shells and of seeds are listed in Tables 40, 41, 42, 43, and 44.

Shade increased the accumulation of total carbohydrates in the shells compared to the control fruits. Low light intensity may affect the transfer of carbohydrate to the testa and seed.

Seeds of control plants had lower percentages of reducing sugar, starch, and sucrose. An increase in starch content of shaded seed is

Table 39. Effects of shade on percentage of oil in seeds.

| Day of fruit formation[a] | Trt | Slope | Intercept | r |
|---|---|---|---|---|
| 52 | C | -0.0079 | 53.910 | -.91 |
| | S | 0.0124 | 29.906 | .81 |
| 59 | C | -0.0004 | 41.569 | -.04 |
| | S | 0.0144 | 26.637 | .65 |
| 66 | C | 0.0139 | 27.780 | .74 |
| | S | 0.0259 | 21.638 | .83 |
| 73 | C | 0.0081 | 34.620 | .52 |
| | S | 0.0112 | 29.900 | .53 |
| 80 | C | 0.0138 | 29.288 | .69 |
| | S | 0.0350 | 16.930 | .98 |

[a] Days after planting from which the pegs were formed. The linear model for these relationships is:

$Y$ = Intercept + slope x $X$
$Y$: oil percentage
$X$: fruit weight in mg.

Table 40. Mean squares and significance levels from the analyses of variance on sucrose and reducing sugar, oil content, and oil percentage of seeds.

| Source | d.f. | Mean Squares | | | |
|---|---|---|---|---|---|
| | | Sucrose | Reducing sugar | Oil | |
| | | mg | mg | % | mg/seed |
| Age(A) | 18 | 503.49*** | .918*** | 108.522*** | 100257.56** |
| Trt(T) | 1 | 1021.002*** | .634** | 123.32*** | 147673.978** |
| AxT | 16 | 105.5*** | .382*** | 75.9*** | 16690.7*** |
| Error | 58 | 31.9 | .111 | 7.4 | 1892.8 |

* P = 0.10
** P = 0.05

*** P = 0.01

Table 41. Mean squares and significance levels from the analyses of variance on sucrose, reducing sugar, starch, total carbohydrates, percent starch, and percent total carbohydrates of peanut seeds.

| Source | d.f. | Mean Square | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sucrose | Reducing sugar | Starch | | Total $CH_2O$ | |
| | | mg | mg | mg | % | mg | % |
| Fruit Wt.(FW) | 1 | 6382.31*** | .289 | 4084.62*** | 55.835*** | 20833.38*** | 89.77*** |
| Trt(T) | 1 | 149.269 | 1.185** | 59.165 | 17.439** | 440.928 | 38.48*** |
| FWxT | 1 | 198.2** | .707 | 3.4 | 8.5 | 170.6 | 23.9*** |
| Error | 90 | 49.9 | .311 | 188.3 | 3.2 | 222.9 | 3.8 |

* P= 0.10
** P = 0.05

*** P = 0.01

Starch content is expressed by glucose-equivalent.

Table 42. Mean squares and significance levels from the analyses of variance on sucrose, reducing sugar, and starch of peanut fruits.

| Source | d.f. | Mean Squares | | | |
|---|---|---|---|---|---|
| | | Sucrose | Reducing sugar | Starch | Total $CH_2O$ |
| | | mg | mg | mg | mg |
| Trt(T) | 1 | 1993.44*** | 0.0217 | 6.56 | .71 |
| Color(C) | 4 | 382.045*** | 30.924 | 326.030*** | 12.45*** |
| Age(A) | 16 | 77.98*** | 202.33*** | 445.156*** | 116.53*** |
| TxC | 4 | 16.639 | 53.86** | 80.15 | 18.66*** |
| TxA | 14 | 181.4*** | 194.35*** | 191.42*** | 176.68*** |
| Error | 54 | 21.9 | 12.16 | 30.09 | 2.08 |

* P= 0.10
** P = 0.05

*** P = 0.01

Reducing sugar is expressed as glucose-equivalent.

Table 43. Mean squares and significance levels from the analyses of variance on sucrose, reducing sugar, and starch (glucose-equivalent) of seeds.

| Source | d.f. | Mean Squares | | | |
|---|---|---|---|---|---|
| | | Sucrose | Reducing sugar | | Starch |
| | | mg | mg | % | mg |
| Trt(T) | 1 | 944.54*** | .70*** | .132*** | 2.752 |
| Color(C) | 4 | 425.88*** | .033 | .007*** | 317.732*** |
| Age(A) | 16 | 346.02*** | .929*** | .054*** | 454.218*** |
| TxC | 4 | 79.17*** | .116 | .005*** | 60.462 |
| TxA | 14 | 131.63*** | .437*** | .0087*** | 192.413*** |
| Error | 54 | 16.10 | .11 | .0012 | 29.447 |

* P = 0.10
** P = 0.05

*** P = 0.01

Reducing sugar is expressed as glucose-equivalent.

Table 44. Mean squares and significance levels from the analyses of variance on sucrose, reducing sugar, and starch (glucose-equivalent) of shells.

| Source | d.f. | Mean Squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sucrose | | Reducing sugar | | Starch | | Total $CH_2O$ | |
| | | mg | % | mg | % | mg | % | mg | % |
| Trt(T) | 1 | 193.614*** | 33.712*** | 0.479 | 1.569 | 0.816** | 0.292*** | 187.77*** | 42.48*** |
| Color(C) | 4 | 6.277 | 0.742 | 32.983 | 2.094 | 0.246 | 0.081*** | 47.51*** | 5.615** |
| Age(A) | 16 | 175.795*** | 16.81*** | 191.275*** | 18.48*** | 3.38*** | 0.617*** | 746.87*** | 79.558*** |
| TxC | 4 | 28.196** | 1.026 | 51.88** | 2.37 | 1.388*** | 0.089*** | 69.65*** | 7.02** |
| TxA | 14 | 186.97*** | 56.62*** | 201.52*** | 25.63*** | 0.75*** | 0.453*** | 703.69*** | 160.111*** |
| Error | 54 | 8.17 | 0.46 | 11.85 | 1.59 | 0.19 | 0.008 | 8.75 | 1.775 |

* P = 0.10

** P = 0.05

*** P = 0.01

in agreement with McNair (1945). He stated that slight shading was found to increase the starch content of flaxseed. Sucrose content (mg per seed) of seeds was higher in control plants of a given age, but the percentage of sucrose in the seeds was lower, because of the greater fruit weight of control plants. Younger seeds contained more starch than the older ones. Shading caused no significant difference in starch content of the seeds; however, the seeds of the control plants tended to store more starch than the shaded seeds. Shade increased reducing sugar of the seeds both in content and percentage (Table 45). In general shaded fruits contained more starch, reducing sugar, and higher percentage of sucrose in seeds than in the control fruits. An increase in percentage of total carbohydrates of the shaded seeds was found in this experiment. This is positively correlated with oil content and oil percentage. Shade may have limited seed growth by its effects on N supply, as carbohydrate levels did not appear limiting in the seeds of shaded plants.

Table 45. Correlation of shade effects on chemical composition of fruit, seed, and shell of peanut.

| Element | Seed | | Shell | | Fruit | |
|---|---|---|---|---|---|---|
| | Signi.[a] diff. | Corr.[b] with shade | Signi.[a] diff. | Corr.[b] with shade | Signi.[a] diff. | Corr.[b] with shade |
| Sucrose | yes | - | yes | + | yes | - |
| Reducing sugar | yes | + | no | - | no | - |
| % reducing sugar | yes | + | no | + | | |
| Starch | no | - | yes | + | no | - |
| % starch | yes | + | yes | + | | |
| Total $CH_2O$ | no | + | yes | + | no | + |
| % total $CH_2O$ | yes | + | yes | + | | |

[a] Significant difference between shade and control at 5% level.

[b] Correlation with shade: + = increase under shade; - = decrease under shade.

# SUMMARY AND CONCLUSIONS

Florunner peanuts were grown in field experiments in two successive years. Three durations of shading were applied at four selected stages of plant development. The objective was to evaluate the effects of low light intensity on total biomass production, flowers, yield components, oil content, and carbohydrate levels, and to determine the critical periods during which low light intensity adversely influencespeanut yield and quality. Pod filling rate and fruit metabolism were also determined. Shade was used to permit 25% of normal sunlight. Flower, peg and pod number, peg and pod dry weight, vegetative parts, and major components of seeds were studied at regular intervals during growth. Vegetative parts of the plants, yield, number, and dry weight of pegs and pods in five categories, and fruit and seed sizes were measured directly.

Development of plants was decreased by shading, but shaded plants recovered following the removal of shades. Low light intensity interrupted peg and pod formation but the rate of pod filling of previously-expanded fruits was maintained at rates somewhat less than those of the control plant fruits. Longer periods of shading (21 days) decreased the fruit filling rate. With short periods of shading during the early season, fruit formation was delayed but recovered after shading. More fruits were formed to compensate for the loss of active flowers during shading. The 75% reduction of light intensity caused an overall average decrease of 66, 85, and 67% of total biomass, vegetative, and reproductive growth rates, respectively. The main effects of shade were contributed to the yield loss at the end of the season. Partitioning of photosynthetic product to reproductive structures was decreased during shading at flowering and pegging stages, but it increased during the pod filling stage, although the yield was lowest as a result of shading at the pod filling stage of growth. Shade not only changed the morphological characteristics of plants, e.g., taller plants, darker, and thinner leaves, it also reduced yield by 20 to 30% and total biomass production by 20 to 25%. Shading for 21 days at pod filling stage reduced yield almost 30%, reduced harvestable fruit number, and delayed fruit growth and decreased the rate of fruit filling. Shade favored the accumulation of starch and reducing sugar in fruit while decreasing sucrose content. Shade appeared to affect the enzymatic process of converting sucrose to starch and reducing sugar in seeds and shells.

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# APPENDIX

## Determination of Oil Sugars and Starch in Peanut

### 1-A: Reducing Sugar and Sucrose in Peanuts

1. Weigh fruits.

2. Separate seeds from fruits.

3. Store shell for grinding step.

4. Weigh seeds and record numbers.

### 2-A: Sugar Extraction from Peanut Shells

1. Grind shells to pass number 20-mesh sieve.

2. Weigh 100 mg of ground shells into a 20 ml test tube.

3. Add 5 ml of 80% ethanol and heat tubes for 30 minutes at 80 C.

4. Repeat the heating step twice on two successive days. Refrigerate between heating steps.

5. Bring to volume, stopped, and shake well.

6. Ethanol solution was decanted to test tubes to save for sugar test.

7. Shell residue was rinsed twice with 80% ethanol, dried, and saved for starch extraction.

### 3-A: Oil Extraction from Peanut Seeds

1. Grind seeds with weighed mortar and pestle.

2. Add 5 ml of petroleum ether to ground seeds, and let stand about 5 minutes. Pipette off the petroleum ether-oil mixture into a weighed beaker. Repeat five times or until petroleum ether remains clear.

3. Combine all petroleum ether and evaporate in a hood until dryness.

4. Dry oil and defatted seed at 60 C until constant weight.

5. Weigh both oil and defatted seed for oil content or oil percentage determination.

6. Save defatted seed for further analysis.

4-A: Sugar Extraction from Defatted Seeds

1. Weigh 100 mg of defatted seed into a 15 ml centrifuge tube.

2. Add 8 ml of 80% ethanol and heat the tube at 80 C for 30 minutes.

3. Centrifuge 10 minutes at 27,000 rpm and decant into 25 ml volumetric flask.

4. Add 8 ml of 80% ethanol and repeat step 2 and 3.

5. Add 8 ml of 80% ethanol and repeat step 2 and 3.

6. Combine the ethanol extracts and bring volumetric to 25 ml with 80% ethanol, stopper, and mix by inversion.

7. Now sugars are extracted, proceed to dilution steps if necessary.

Note: Keep the sugar solution overnight in freezer

## Carbohydrate Procedures

### 5-A: Determination of Total Sugars in Peanut Shell and Peanut Seed

1. Transfer 1 ml of ethanol extract or diluted sugar solution containing approximately 0.02 to 0.08 mg glucose-equivalent to 10 ml scored test tube.

2. Evaporate the ethanol sugar solution until dryness.

3. Add 1 ml of distilled water to each tube.

4. Add 1 ml of invertase mix into each tube, mix, and incubate for 90 minutes at room temperature.

5. Continue with step 4 of reducing sugar procedure (6-A).

Note: Followed the same procedure for sugar standards every time to develop a standard curve.

## 6-A: Nelson's Test for Determination of Reducing Sugars

Procedure:

1. Transfer 1 ml of ethanol extract or diluted sugar solution containing approximately 0.02 to 0.08 mg glucose-equivalent to 10-ml scored test tubes.
2. Evaporate the ethanol until dryness.
3. Add 1 ml of distilled water to each tube.
4. Add 1 ml of Alkaline reagent (Copper reagent) and shake well.
5. Heat in boiling water bath for 30 minutes.
6. Cool the tubes in iced water.
7. Add 1 ml Arsenomolybdate reagent, mix, and shake well.
8. Add distilled water up to 10 ml in all tubes and mix by vortex.
9. Read absorbance at 540 nm (green filter) with the blank as zero.

Reagents:

1. Alkaline reagent. Dissolve 25.0 g Anhydrous Sodium Carbonate, 25.0 g Potassium Sodium Tartrate, 20.0 g Sodium Bicarbonate, and 200.0 g Anhydrous Sodium Sulfate in 700 ml distilled water, and then dilute to 1000 ml. Dissolve 6.0 g Cupric Sulfate (pentahydrate) in 40.0 ml distilled water followed by one drop of concentrated sulfuric acid. Combine and mix the two solutions.
2. Arsenomolybdate reagent. Dissolve 25.0 g Ammonium Molybdate Tetrahydrate in 450 ml distilled water, then add 21 ml concentrated Sulfuric Acid. Dissolve 3.0 g Disodium Arsenate in 25 ml distilled water. Combine and mix the two solutions and store in brown bottle for 24 hours at 37 C. Reagent should be yellow with no green tint.

Before using, prepare the arsenomolybdate mix by: 2 parts of 1.5N Sulfuric Acid, 1 part of arsenomolybdate reagent. Store in automatic repipette, and ready to use.

3. Glucose standard. Dissolve 100 mg glucose in 1000 ml distilled water. Use zero to 1 ml of standard glucose to develop standard curve.

Comments:

1. Arsenomolybdate reagent is easily contaminated by metal surfaces, avoid metal syringes, bottle caps, etc.

2. Store arsenomolybdate mix in dark until using.

3. Glucose standard can be used for fructose.

4. Invertase mix for total sugar test: 1 ml of invertase concentrate*, 3 ml of Acetate buffer, and 25 ml of distilled water. Prepare invertase mix prior to use.

5. Save sugar solutions overnight in freezer.

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* Invertase concentrate was extracted from yeast and stabilized with glycerol. One ml enzyme reduces optical rotation of 4 g sucrose in 20 ml of M/10 $NaH_2PO_4$ to zero within 30 minutes at 30 C.

## 7-A: Amyloglucosidase Procedure for Hydrolyzing Starch

Procedure:

1. Dry residue remaining after 80% ethanol extraction in the oven at 60 C overnight.

2. Grind in 5 ml 0.1 N acetate buffer. Pour into 15 ml centrifuge tubes.

3. Wash the grinder with 5 ml of 0.5% enzyme solution in 0.1 N acetate buffer.

4. Stopper, mix, and incubate at 41 C for 48 hours.

5. Centrifuge at 15,000 rpm in SM 24 rotor for 30 minutes, and decant into numbered test tubes.

6. Save aliquot for reducing sugar determination of glucose-equivalent.

Reagents:

1. Acetate buffer 0.2 N (pH 4.5). Mix: 3 parts of 0.2 N acetic acid and 2 parts of 0.2 N sodium acetate. Add a few crystals of thymol* to prevent microorganism growth.

    a. 0.2 N Acetic acid: dilute 11.45 ml of glacial acetic acid (99.5% pure) to 1 liter with distilled water to make 1 liter.

    b. 0.2 N Sodium acetate: dissolve 16.4 g Anhydrous sodium acetate in distilled water to make 1 liter.

2. 0.5% Amyloglucosidase solution. Add 5.0 g amyloglucosidase (alpha 1,4-glucan hydrolase E.C. No. 3.2.1.3. Rhizopus) to 1 liter distilled water or acetate buffer. Add a few crystals of thymol* and store in brown bottle.

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* Thymol: dissolve 3-4 crystals in a 2 or 3 ml of ethanol prior to adding to aqueous solution.

Notes:

1. Mix the centrifuge tubes thoroughly 3 or 4 times during incubation.

2. Mix the tubes prior to centrifuging.

3. Mix and prepare the amyloglucosidase solution freshly prior to use.

Reference:

Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissues. Wisconsin Res. Report No. 41.

# BIOGRAPHICAL SKETCH

Hang Ngoc An was born on December 10, 1942, in Cholon, South Vietnam. She attended elementary, secondary, and high school in Saigon. In May 1963, she graduated from Gialong High School. In September 1968, she received the degree "Ky-Su Nong-Khoa" (Engineer of Agriculture) from the National Agricultural Institute (NAI), Saigon, Vietnam.

From September 1968 until August 1969, she worked as a Research Assistant at the College of Agriculture, NAI. From September 1969 until December 1969, she worked for the Ministry of Agriculture, Saigon. In December 1969, after transferring to the NAI, she served as teaching and research instructor. During this period, she was invited to serve as visiting lecturer of the Cao-Dai University.

Following the service to NAI, College of Agriculture, she received a scholarship from the Ministry of Education for University Professor Training Program and an assistantship from the Department of Agronomy to pursue a graduate program at the University of Florida.

In March 1976, she received the degree of Master of Science with a major in Agronomy and a minor in Soil Science at the University of Florida, and has been working since then toward the degree of Doctor of Philosophy in the same department.

She is a member of American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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D. E. McCloud, Chairman
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June 1978

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